2018

SCIENCE & ENGINEERING INDICATORS

NATIONAL SCIENCE BOARD

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Front Matter

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About Science and Engineering Indicators

Science and Engineering Indicators (Indicators) is a congressionally mandated report that provides high-quality quantitative information on the U.S. and international science and engineering enterprise. *Indicators* is factual and policy neutral. It does not offer policy options, and it does not make policy recommendations. The report employs a variety of presentation styles—such as narrative text, data tables and figures—to make the data accessible to readers with different information needs and different information-processing preferences.

The data are “indicators,” that is, quantitative summary information on the scope, quality, and vitality of the science and engineering (S&E) enterprise or its change over time. The indicators in this report are intended to contribute to an understanding of the current environment and to inform the development of future policies. The report does not model the dynamics of the S&E enterprise. It is used by readers for a variety of purposes, and they have different views about which indicators are the most significant for different purposes.

Indicators is prepared under the guidance of the National Science Board by the National Center for Science and Engineering Statistics (NCSES), a federal statistical agency within the National Science Foundation (NSF), Social, Behavioral and Economic Sciences Directorate. The report is subject to extensive review by internal and external subject matter experts, federal agencies, Board members, and NCSES statistical reviewers for accuracy, coverage, and balance.

Indicators includes detailed information about measurement to help readers understand what the reported measures mean, how the data were collected, and how to use the data appropriately. The report’s data analyses, however, are relatively accessible. The data can be examined in various ways, and the report generally emphasizes neutral, factual description. As a result, *Indicators* almost exclusively uses simple statistical tools. The Methodology Appendix of the report provides detailed information on the methodological, statistical, and data-quality criteria used for the report. The sidebar What Makes a Good Indicator? provides a brief and high-level summary of the data sources used in the report and data-quality issues that influence the interpretation and accuracy of the information presented in *Indicators*.

Indicators 2018 Parts

Indicators 2018 includes an Overview and eight chapters that follow a generally consistent pattern. The chapter titles are as follows:

- Elementary and Secondary Mathematics and Science Education
- Higher Education in Science and Engineering
- Science and Engineering Labor Force
- Research and Development: U.S. Trends and International Comparisons
- Academic Research and Development
- Industry, Technology, and the Global Marketplace
- Science and Technology: Public Attitudes and Understanding
- Invention, Knowledge Transfer, and Innovation

In addition, *Indicators 2018* includes an online data tool, State Indicators, which provides state-level data on science and technology (S&T); and a Digest, comprising a small selection of important indicators from the main report.

The Board authors one or more companion pieces, which draw on the data in *Indicators* and offer recommendations on various issues related to national science and engineering research or education policy, in keeping with the Board's statutory responsibility to bring attention to such issues.

The Digest

The *Science and Engineering Indicators 2018 Digest* is a condensed version of the report comprising a small selection of important indicators. It is intended to serve readers with varying levels of expertise. The Digest draws attention to important trends and data points and introduces readers to the data resources available in the main report and associated products.

The Overview of the State of the U.S. S&E Enterprise in a Global Context

The Overview highlights information from *Science and Engineering Indicators* that offers insights into the global landscape and presents broadly comparable data to examine indicators across regions, countries, and economies. Like the Digest, the Overview is intended to serve readers with varying levels of expertise. Because the Overview relies heavily on figures, it is well-adapted for use in developing presentations. Like the core chapters, the Overview strives for a descriptive synthesis and a balanced tone, and it does not take or suggest policy positions.

The Eight Core Chapters

Each chapter consists of highlights; introduction (chapter overview and chapter organization); a narrative synthesis of data and related contextual information; sidebars, data tables, and figures; conclusion; notes; glossary; and references.

Highlights. The highlights outline the major dimensions of a chapter topic.

Introduction. The chapter's overview briefly explains the importance of the topic. It situates the topic in the context of major concepts, terms, and developments relevant to the data reported. The introduction includes a brief narrative account of the logical flow of topics within the chapter.

Narrative. The chapter narrative is a descriptive synthesis that brings together significant findings. It is also a balanced presentation of contextual information that is useful for interpreting the findings. The narrative is designed to draw attention to major points and enable readers to readily comprehend a large amount of information. As a balanced presentation, the narrative aims to include appropriate caveats and context to convey appropriate uses of the data and provide contextual information within which the data may be interpreted by users with a range of science policy views.

Figures. Figures provide visually compelling representations of major findings discussed in the text. Figures also enable readers to test narrative interpretations offered in the text by examining the data themselves.

Tables. Data tables help to illustrate and to support points made in the text.

Sidebars. Sidebars discuss interesting recent developments in the field, more speculative information than is presented in the regular chapter narrative, or other special topics. Sidebars can also present definitions or highlight crosscutting themes.

Appendix Tables. An appendix of tabular data provides the most complete presentation of quantitative data, without contextual information or interpretive aids.

Conclusion. The conclusion summarizes important findings. It offers a perspective on important trends but stops short of definitive pronouncements about either likely future trends or policy implications. Conclusions avoid factual syntheses that suggest distinctive or controversial viewpoints.

Notes. Information that augments points of discussion in the text is presented as endnotes.

Glossary. The glossary defines terms used in the chapter.

References. *Indicators* includes references to data sources cited in the text, emphasizing national or internationally comparable data. The report does not attempt to review the analytic literature on a topic or summarize the social science or policy perspectives that might be brought to bear on it. References to that literature are included where they help to explain the basis for statements in the text.

State Indicators Data Tool

This online tool provides data to assess trends in S&T-related activities in states that can be used by people involved in state-level policy making, journalists, and interested citizens. State-level indicators to call attention to state performance in S&T and foster consideration of state-level activities in this area. Data for the indicators are graphically displayed in tables that detail state data, in U.S. maps that code states into quartiles, and in histograms that show how state values are distributed. Users also have access to long-term trend data for each indicator.

Presentation

The complete content of *Indicators 2018* is available for download. The report is downloadable as a PDF and text tables, appendix tables, and source data for each figure are available in PDF and spreadsheet formats. In addition, figures are also available in presentation-style image files.

Letter of Transmittal

National Science Board

January 15, 2018

MEMORANDUM FROM THE CHAIR OF THE NATIONAL SCIENCE BOARD

TO: The President and Congress of the United States

SUBJECT: Science and Engineering Indicators 2018

As Chair of the National Science Board (Board), it is my honor to transmit, on behalf of the Board, *Science and Engineering Indicators* (*Indicators*) *2018*. The Board submits this biennial report "on indicators of the state of science and engineering in the United States" as required by 42 U.S.C. § 1863 (j) (I). The *Indicators* series provides a broad base of unbiased, quantitative information about the U.S. science and engineering (S&E) enterprise for use by policymakers, researchers, and the public.

The digital report includes information on science, technology, engineering, and mathematics (STEM) education at all levels; the scientific and engineering workforce; U.S. and international research and development performance; U.S. competitiveness in high-technology industries; and public attitudes and understanding of S&E. The report synthesizes several key indicators of the strength of U.S. science and technology in an "Overview of the State of the U.S. S&E Enterprise in a Global Context." *Indicators 2018* also includes an interactive, online tool that enables state comparisons on a variety of S&E indicators.

For the 2018 edition, the Board has introduced a new chapter on "Invention, Knowledge Transfer, and Innovation." This chapter provides data and analysis on several key questions: how does innovation happen; how do we measure it; who are the major players; and how does innovation diffuse through society and economies to contribute to economic growth?

The Board hopes that the Administration and Congress find the information and analysis in the report useful and timely for the planning of national priorities, policies, and programs in science and technology.

Maria T. Zuber

Chair

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Front Matter

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Image Credit

The website for *Science and Engineering Indicators 2018 incorporates* a polarization microscope image of liquid crystals. Liquid crystals revolutionized how we present information, giving rise to the liquid crystal display (LCD) industry. Modern devices including smartphones, laptop screens, and flat-panel television sets all feature LCDs, in which so-called nematic ("threadlike") liquid crystals realign in an electric field, thus changing the appearance of the pixelated screen.

In the photo, the two dark centers with emerging streamers are called "boojum," point defects in the molecular orientation of the liquid crystal. The defects form at the surface of a thin film of nematic fluid, the simplest form of a liquid crystal. The bands of different colors show the varying orientation of liquid crystal molecules around the defect.

This image was created by Oleg D. Lavrentovich, Trustees Research Professor, Liquid Crystal Institute and Chemical Physics Interdisciplinary Program, Kent State University. Work at the Liquid Crystal Institute explores the physical mechanisms behind the complex, three-dimensional molecular architectures and the practical applications of these materials. Research in liquid crystals at Kent State University has been supported by a series of National Science Foundation grants (the most recent is NSF award number 17-29509).

Image credit: *Oleg D. Lavrentovich, Liquid Crystal Institute, Kent State University.*

Key to Acronyms and Abbreviations

ACGR: adjusted cohort graduation rate

ACS: American Community Survey

ACS: American Competitiveness Survey

ADEA: Age Discrimination in Employment Act of 1967

AFFOA: Advanced Functional Fabrics of America

AFGR: averaged freshman graduation rate

ANBERD: Analytical Business Enterprise R&D

AP: Advanced Placement

ARC: Average of Relative Citations

ARM: Advanced Robotics for Manufacturing

ARMI: Advanced Regenerative Manufacturing Institute

ARPA-E: Advanced Research Projects Agency–Energy

ARRA: American Recovery and Reinvestment Act

AUTM: Association of University Technology Managers

BEA: Bureau of Economic Analysis

BLS: Bureau of Labor Statistics

BPS: Beginning Postsecondary Students

BRDIS: Business R&D and Innovation Survey

CAGR: compound average annual growth rate

C-BERT: Cross-Border Education Research Team

CEMI: Clean Energy Manufacturing Initiative

CIS: Community Innovation Survey

CPS: Current Population Survey

CRADA: cooperative R&D agreement

CRDC: Civil Rights Data Collection

CREDO: Center for Research on Education Outcomes

DHS: Department of Homeland Security

DMDII: Digital Manufacturing and Design Innovation Institute

DOAJ: Directory of Open Access Journals

DOC: Department of Commerce

DOD: Department of Defense

DOE: Department of Energy

Front Matter

EACEA: Education, Audiovisual and Culture Executive Agency

EC: European Commission (Overview)

ECDS: Early Career Doctorates Survey

ECLS-K: Early Childhood Longitudinal Study-Kindergarten

ED: Department of Education

EPA: Environmental Protection Agency

EPSCoR: Established Program to Stimulate Competitive Research

ESSA: Every Student Succeeds Act

EU: European Union

FDI: foreign direct investment

FedScope: Federal Human Resources Data

FFRDC: federally funded research and development center

FLC: Federal Laboratory Consortium for Technology Transfer

FTE: full-time equivalent

FY: fiscal year

G20: Group of Twenty

GAO: Government Accountability Office

GBARD: government budget appropriations for R&D

GDP: gross domestic product

GE: genetically engineered

GED: General Educational Development

GERD: gross domestic expenditures on R&D

GHG: greenhouse gas

GM: genetically modified

GMO: genetically modified organism

GMU: George Mason University

GPT: general purpose technology

GSS: General Social Survey

GSS: Survey of Graduate Students and Postdoctorates in Science and Engineering

GUF: general university fund

HBCU: historically black college or university

HDI: Human Development Index

HE: higher education

HERD: Higher Education Research and Development Survey

HHE: High Hispanic enrollment

HHS: Department of Health and Human Services

HPC: high-performance computing

HS: Harmonized Commodity Description and Coding System, or Harmonized System

HSI: Hispanic-serving institution

HSLS: High School Longitudinal Study

HT: high technology

IACMI: Institute for Advanced Composites Manufacturing Innovation

IB: International Baccalaureate

ICT: information and communications technologies

IDeA: Institutional Development Award

IEA: International Association for the Evaluation of Educational Achievement

IEA: International Energy Agency

IIE: Institute of International Education

IMF: International Monetary Fund

IOF: involuntarily out-of-field

IoT: Internet of Things

IPC: International Patent Classification

IPEDS: Integrated Postsecondary Education Data System

IPO: initial public offering

IPUMS: Integrated Public Use Microdata Series

IRC: Internal Revenue Code

IRS: Internal Revenue Service

ISCED: International Standard Classification of Education

ISCED-F: ISCED Fields of Education and Training

ISIC: International Standard Industrial Classification of All Economic Activities

ISO: International Organization for Standardization

IT: information technology

ITC: Investment Tax Credit

IUCRC: Industry–University Cooperative Research Centers Program

K–12: kindergarten through 12th grade

KI: knowledge intensive

KTI: knowledge- and technology-intensive

LIFT: Lightweight Innovations for Tomorrow

Front Matter

MEP: Manufacturing Extension Partnership

MER: market exchange rate

MFP: multifactor productivity

MHT medium-high technology

MIT: Massachusetts Institute of Technology

MNC multinational corporation

MNE: multinational enterprise

MOOC: massive open online course

MSI: minority-serving institution

NAEP: National Assessment of Educational Progress

NAFTA: North American Free Trade Agreement

NAGB: National Assessment Governing Board

NAICS: North American Industry Classification System

NASA: National Aeronautics and Space Administration

NASF: net assignable square feet

NCES: National Center for Education Statistics

NCRPA: National Cooperative Research and Production ActNCSES: National Center for Science and Engineering Statistics

NCTQ: National Center for Teaching Quality

nec: not elsewhere classified

NECTA: New England City and Town Area

NEH: National Endowment for the Humanities

NELS: National Education Longitudinal Study

NGA: National Governors Association

NGSS: Next Generation Science Standards

NIH: National Institutes of Health

NIIMBL: National Institute for Innovation in Manufacturing Biopharmaceuticals

NIPA: national income and product accounts

NIST: National Institute of Standards and Technology

NLR: National Lambda Rail

NLS: National Longitudinal Study

NOAA: National Oceanic and Atmospheric Administration

NPL: nonpatent literature

NPSAS: National Postsecondary Student Aid Study

NRC: National Research Council

NSB: National Science Board

NSCG: National Survey of College Graduates

NSCI: National Strategic Computing Initiative

NSF: National Science Foundation

NSLP: National School Lunch Program

NSRCG: National Survey of Recent College Graduates

NTIA: National Telecommunications and Information Administration

NTPS: National Teacher and Principal Survey

OA: open access

OECD: Organisation for Economic Co-operation and Development

OES: Occupational Employment Statistics

ONP: other nonprofit organization

OPEC: Organization of the Petroleum Exporting Countries

OPM: Office of Personnel Management

OPT: optional practical training

OSTP: Office of Science and Technology Policy, Executive Office of the President

OWH: other Western Hemisphere

PISA: Program for International Student Assessment

PPP: purchasing power parity

PSM: Professional Science Master's

PST: professional, scientific, and technical

PTC: Production Tax Credit

R&D: research and development

R&E: research and experimentation

RA: research assistantship

RAPID: Rapid Advancement in Process Intensification Deployment

RC: relative citation

RD&D: research, development, and demonstration

REMADE: Reducing Embodied-energy and Decreasing Emissions in Materials Manufacturing

ROW: rest of world

S&E: science and engineering

S&T: science and technology

SASS: Schools and Staffing Survey

SBA: U.S. Small Business Administration

SBIR: Small Business Innovation Research

SciELO: Scientific Electronic Library Online

SDR: Survey of Doctorate Recipients

SED: Survey of Earned Doctorates

SEH: science, engineering, and health

SEP: standard essential patent

SES: socioeconomic status

SESTAT: Scientists and Engineers Statistical Data System

SET: science, engineering, and technology

SEVIS: Student and Exchange Visitor Information System

SOC: Standard Occupational Classification

STEM: science, technology, engineering, and mathematics

STTR: Small Business Technology Transfer

TA: teaching assistant

TCU: tribal college or university

TEL: technology and engineering literacy

TFP: total factor productivity

TIMSS: Trends in International Mathematics and Science Study

UIS: UNESCO Institute for Statistics

UK: United Kingdom

UN: United Nations

UNESCO: United Nations Educational, Scientific and Cultural Organization

URM: underrepresented minority (black or African American, Hispanic or Latino, and American Indian or Alaska Native)

USCIS: U.S. Citizenship and Immigration Services

USDA: Department of Agriculture

USPTO: U.S. Patent and Trademark Office

WebCASPAR: Integrated Science and Engineering Resources Data System

WIPO: World Intellectual Property Organization

WTO: World Trade Organization

XSEDE: Extreme Science and Engineering Discovery Environment

Overview of the State of the U.S. S&E Enterprise in a Global Context

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Introduction

The global landscape of S&E research, education, and business activities has undergone dramatic shifts since the turn of the twenty-first century, as regions, countries, and economies around the globe continue to invest in science and technology (S&T). S&E capabilities, until recently located mainly in the United States, Western Europe, and Japan, have spread to the developing world, notably to China and other Southeast Asian economies that are heavily investing to build their S&T capabilities. This Overview examines how these changing S&E patterns affect the position of the United States relative to the other major global players.

Science and Engineering Indicators describes international and domestic S&E dynamics in light of the worldwide trend toward more knowledge-intensive economies and both increasing global collaboration and competition in S&E. In knowledge-intensive economies, S&E research, its commercial utilization, and other intellectual work are of growing importance. Increasingly, economies rely on a skilled workforce and sustained investment in R&D to produce knowledge streams, new technologies, and discoveries. The resulting knowledge and discoveries lead to new or improved products and processes, as well as output growth in many industries, notably manufacturing industries that produce spacecraft, pharmaceuticals, and computers or in the sizable financial, business, education, and health services sectors.

Knowledge-intensive production is growing worldwide and is increasingly a feature of both developed and developing economies. The goods and services of these industries, many of them new in this century, have developed markets that did not exist previously. Such goods and services have helped to integrate nations into, and to compete in, the global marketplace. The state of S&E in the United States and elsewhere is not just a function of a given nation's policies and investments. Education, R&D, and production activities are interlinked in today's knowledge economies. Globally mobile students and researchers, international trade, global supply chains and investments, and global infrastructure and collaboration tie activities across the globe and shape *national* S&E stories. The various *national* S&E stories together tell a broader and more *global* S&E story.

This overview highlights information from *Science and Engineering Indicators* that offers insights into the global landscape and presents broadly comparable data to examine indicators across regions, countries, and economies, comparing S&E training, research outputs, the creation and use of intellectual property, and the output of knowledge-intensive industries. It is not intended to be comprehensive: numerous important topics that are addressed in individual chapters are not covered in the overview: K–12 mathematics and science education, demographic profiles of those participating in S&E education and occupations, and public attitudes and understanding of S&T. Major findings on particular topics can be found in the "Highlights" sections that appear at the beginning of Chapters 1–8.[1]

One factor that is prominent throughout the Overview is the robust growth trends experienced by developing countries, particularly China, compared to the United States and the rest of the developed economies in the world. Rapid growth rates frequently accompany the early stages of economic and technical development, slowing as societies mature. As developing nations focus resources in R&D, education, and knowledge-intensive production and trade, their initially rapid growth rates in these areas can exceed those of developed nations and thus open up the possibility to move toward developed world measures. Whether and how long these differential growth rates continue is an important question and will be affected by the overall S&E environment, along with the economic, social, and political forces that influence it.

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[1] See sidebar What Makes a Good Indicator? for a brief and high-level summary of the data sources used in the *Science and Engineering Indicators* (*Indicators*) report and the data quality issues that influence the interpretation and accuracy of the information presented in *Indicators*.

Workers with S&E Skills

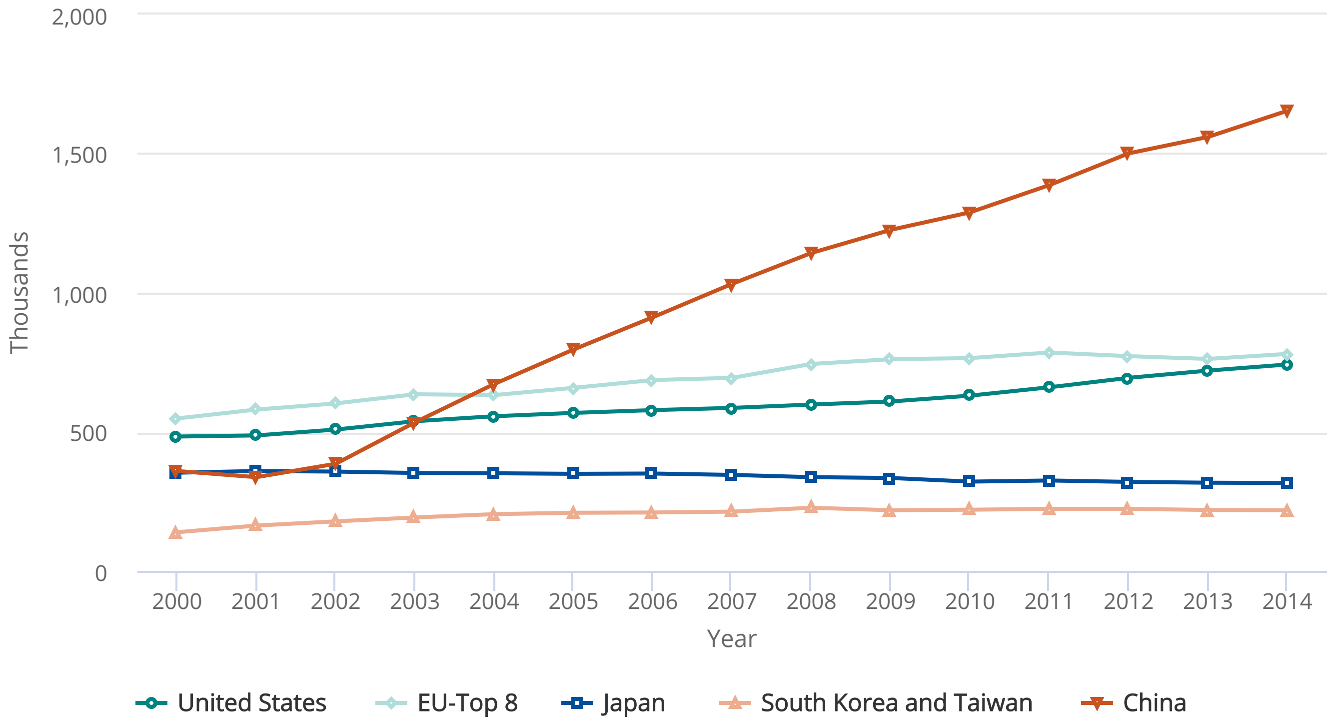
An innovative, knowledge-based economy requires a workforce with high-levels of S&E skills and an education system that can produce such workers in sufficient numbers. Realizing this, governments in many countries prioritized increased access to S&E-related postsecondary education. At the same time, countries compete to attract the best talent (OECD 2017), leading to increased mobility of high-skill workers. Comprehensive and internationally comparable data on the global S&E workforce, while limited, suggest that S&E work is increasingly occurring throughout the world with concentrations in specific regions.

Globally, first university degree awards in S&E fields, broadly equivalent to a bachelor's degree, totaled more than 7.5 million, according to the most recent estimates. Almost half of these degrees were conferred in two Asian countries: India (25%) and China (22%); another 22% together were conferred in the European Union (EU; see Glossary for member countries) (12%) and in the United States (10%). University degree production in China has grown faster than in other major developed nations and regions (Figure O-1). Between 2000 and 2014, the number of S&E bachelor's degrees awarded in China rose more than 350%, significantly faster than in the United States and in many other European and Asian regions and economies. Additionally, during the same period, the number of non-S&E degrees conferred in China also rose dramatically (by almost 1,200%), suggesting that capacity building in China, as indicated by bachelor's degree awards, is occurring in both S&E and non-S&E areas.

Overview of the State of the U.S. S&E Enterprise in a Global Context

FIGURE O-1

Bachelor's degree awards in S&E fields, by selected region, country, or economy: 2000–14



EU = European Union.

Note(s)

Data are not available for all countries for all years. EU-Top 8 includes the eight EU countries with the largest numbers of bachelor's degree awards in 2014: United Kingdom, Germany, France, Poland, Italy, Spain, Romania, and the Netherlands.

Source(s)

United Nations Educational, Scientific and Cultural Organization (UNESCO), Institute for Statistics database, special tabulations (2016); Organisation for Economic Co-operation and Development (OECD), OECD.Stat, https://stats.oecd.org/; National Bureau of Statistics of China, *China Statistical Yearbook,* annual series (Beijing) (various years); Government of India, Ministry of Human Resource Development, Department of Higher Education 2008, Education Statistics at a Glance 2005–06 and All India Survey on Higher Education 2011–12 (2014) and 2014–15 (2016); Government of Japan, Ministry of Education, Culture, Sports, Science and Technology, Survey of Education, annual series (various years); Ministry of Education, *Educational Statistics of the Republic of China (Taiwan),* annual series (various years); National Center for Education Statistics, Integrated Postsecondary Education Data System (IPEDS), Completions Survey; National Science Foundation, National Center for Science and Engineering Statistics, Integrated Science and Engineering Resources Data System (WebCASPAR), https://ncsesdata.nsf.gov/webcaspar/.

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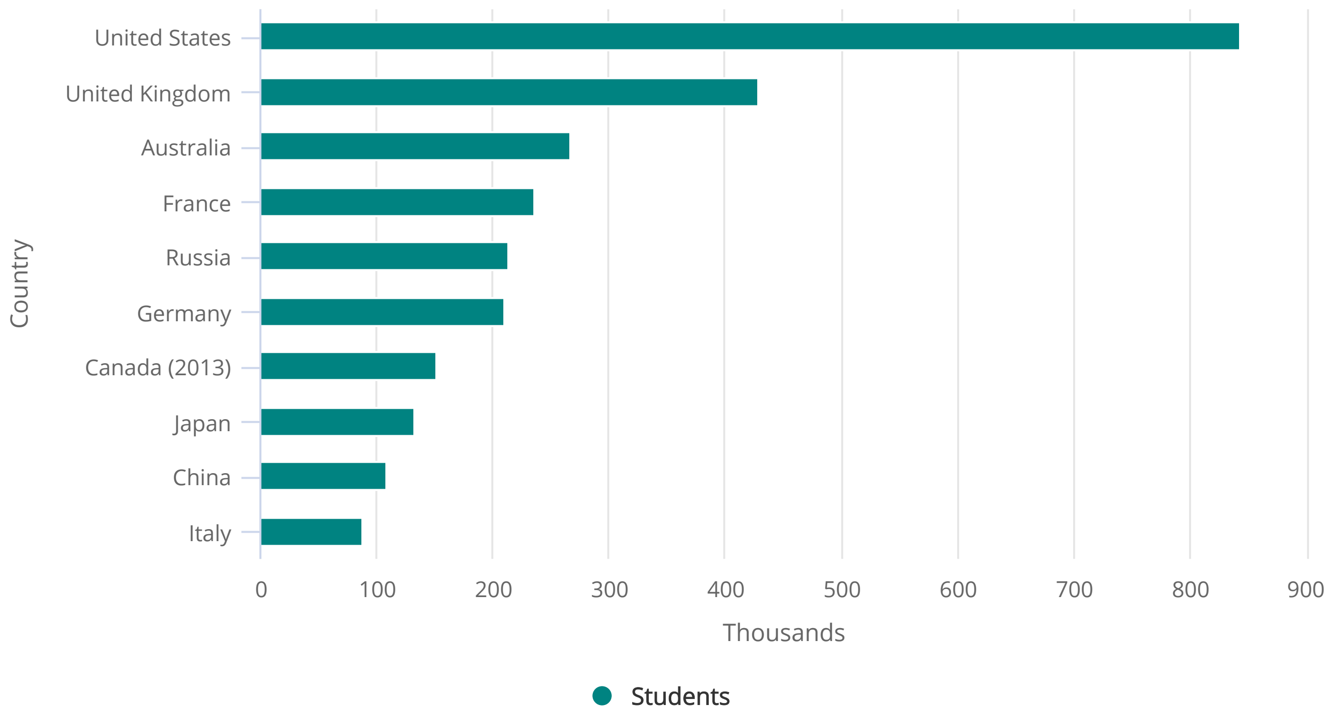
Understanding the relationship between degrees conferred in a country and the capabilities of its workforce is complicated by the fact that increasing numbers of students are receiving higher education outside their home countries.[1] The United States remains the destination of choice for the largest number of internationally mobile students worldwide. Furthermore, international students accounted for a considerable increase over time in U.S. higher education degree awards in S&E fields. Yet, due in part to efforts by other countries to attract more foreign students, the share of the world's internationally mobile students enrolled in the United States fell from 25% in 2000 to 19% in 2014. Other popular destinations for internationally mobile students are the United Kingdom, Australia, France, Russia, and Germany (Figure O-2).

FIGURE O-2

Internationally mobile students enrolled in tertiary education, by selected country: 2014



Note(s)

Data are based on the number of students who have crossed a national border and moved to another country with the objective of studying (i.e., mobile students). Data include students in all fields, including S&E and non-S&E fields. Data for Canada correspond to 2013.

Source(s)

United Nations Educational, Scientific and Cultural Organization (UNESCO), Institute for Statistics database, special tabulations (2016).

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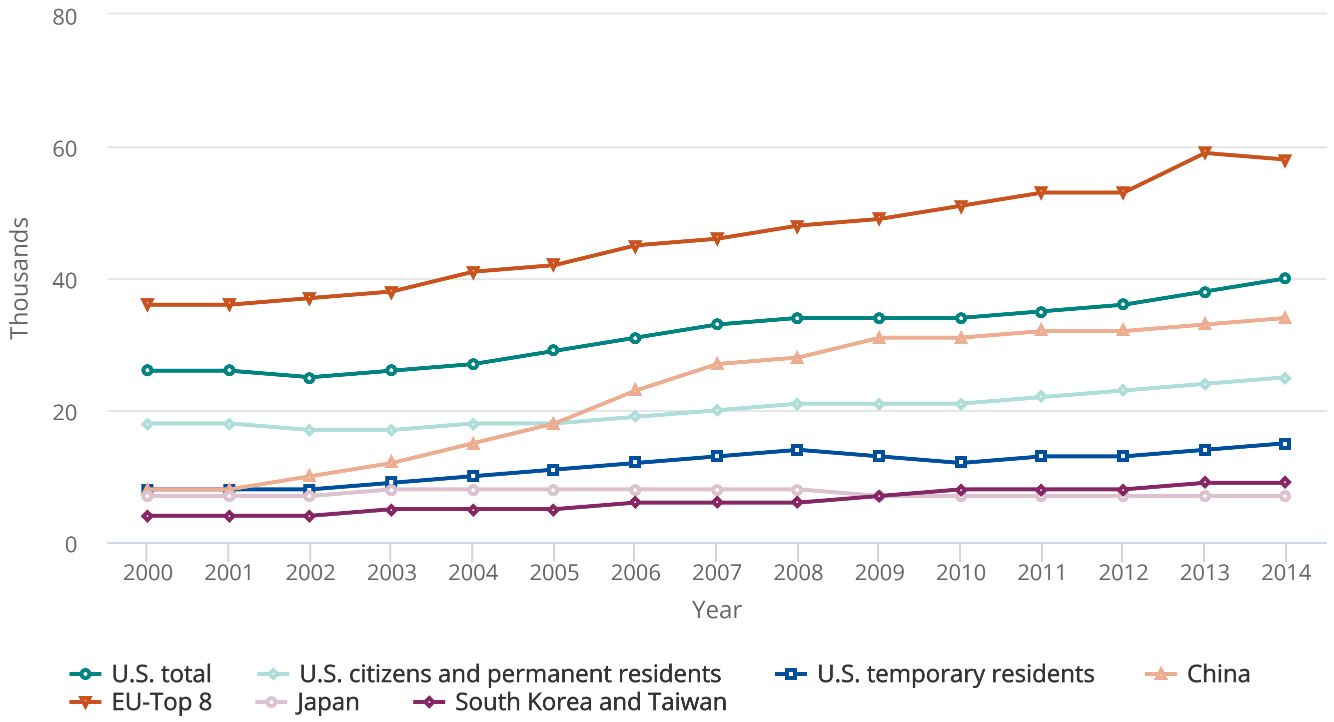
Graduate education in the United States remains particularly attractive to international students. Unlike S&E bachelor's-level degrees, the United States as well as the combined EU countries award a relatively large number of worldwide S&E doctorates (Figure O-3). However, starting from a low base, China has seen a rapid increase in S&E doctoral degree awards over time.

FIGURE O-3

Doctoral degree awards in S&E fields, by selected region, country, or economy: 2000–14



EU = European Union.

Note(s)

U.S. citizens and permanent residents and U.S. temporary residents are estimated using their represented shares in the Integrated Postsecondary Education Data System (IPEDS). EU-Top 8 includes the eight EU countries with the largest numbers of doctoral degree awards in 2014: Germany, United Kingdom, France, Spain, Italy, Portugal, Sweden, and Romania.

Source(s)

United Nations Educational, Scientific and Cultural Organization (UNESCO), Institute for Statistics database, special tabulations (2016); Organisation for Economic Co-operation and Development (OECD), OECD.Stat, https://stats.oecd.org/; National Bureau of Statistics of China, *China Statistical Yearbook,* annual series (Beijing) (various years); Government of India, Department of Science and Technology (various years) and Ministry of Human Resource Development, Department of Higher Education, All India Survey on Higher Education 2011–12 (2014) and 2014–15 (2016); Government of Japan, Ministry of Education, Culture, Sports, Science and Technology, Survey of Education, annual series (various years); Ministry of Education, *Educational Statistics of the Republic of China (Taiwan),* annual series (various years); National Center for Education Statistics, IPEDS, Completions Survey; National Science Foundation, National Center for Science and Engineering Statistics, Integrated Science and Engineering Resources Data System (WebCASPAR), https://ncsesdata.nsf.gov/webcaspar/.

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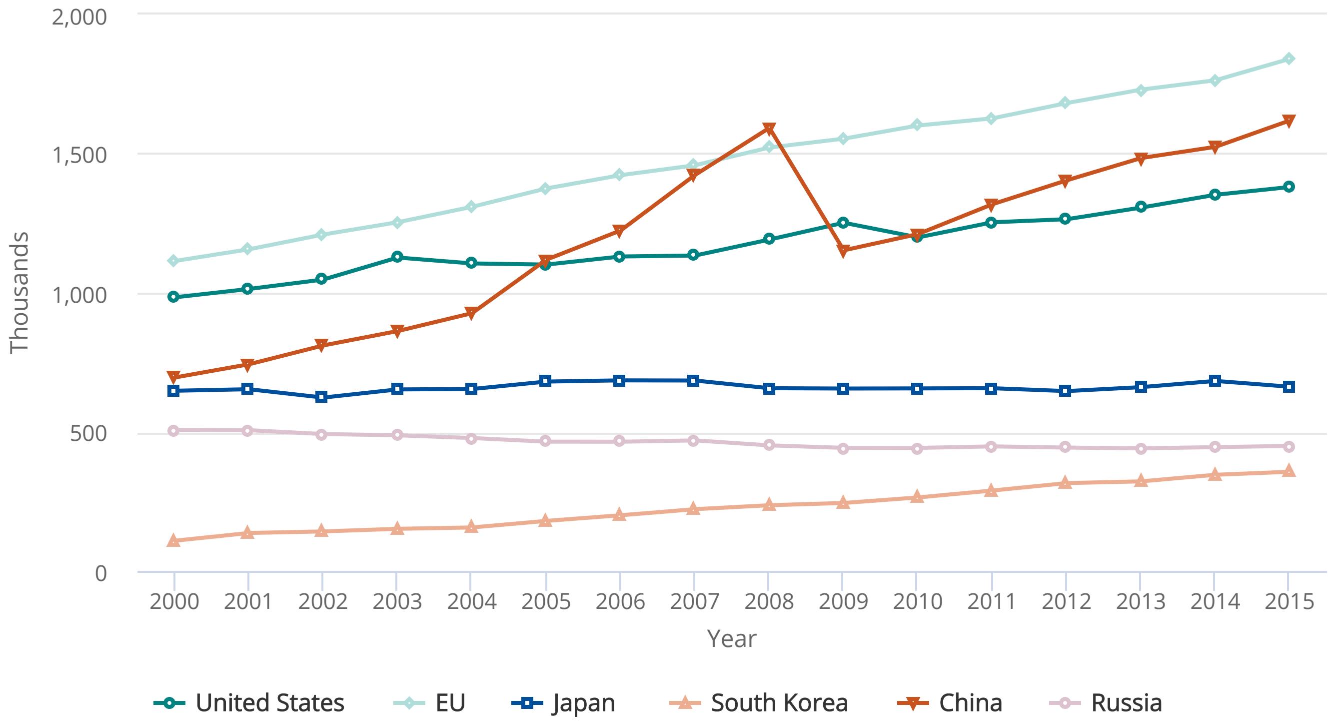
In the United States, a substantial proportion of S&E doctoral degrees are conferred to international students with temporary visas. In 2014, temporary visa holders, not counting foreign-born students with permanent visas, earned more than one-third (37%) of S&E doctoral degrees. Temporary visa holders are particularly concentrated in engineering, computer sciences, mathematics, and economics, earning half or more of the doctoral degrees awarded in these fields. Overall, a considerable share of the post-2000 increase in U.S. S&E doctoral degree awards reflects degrees awarded to temporary visa holders, mainly from Asian countries such as China and India. If past trends continue, a majority of the S&E doctorate recipients with temporary visas—more than two-thirds—will remain in the United States for subsequent employment. The stay rates of those from China and India, the two largest source countries for international recipients of U.S. S&E doctoral degrees, however, have declined slightly since the turn of the century.

These doctorate recipients add to the most highly trained segment of the overall global S&E workforce. It is difficult to analyze the size of the entire international S&E workforce because comprehensive, internationally comparable data are limited. The Organisation for Economic Co-operation and Development (OECD) provides international estimates on one particularly salient component of this workforce—researchers—defined as “professionals engaged in the conception or creation of new knowledge” who “conduct research and improve or develop concepts, theories, models, techniques instrumentation, software or operational methods” (OECD 2015:379). Although national differences in these estimates may be affected by survey procedures and interpretations of international statistical standards, they can be used to make broad comparisons of national trends on this highly specialized component of the larger S&E workforce.

The United States and the EU continue to enjoy a distinct but decreasing advantage in the supply of human capital for research and other work involving S&E. Similar to trends seen in S&E doctoral degree awards, in absolute numbers, these two regions had the largest populations of researchers at the latest count, but China has been catching up (📊Figure O-4).

FIGURE O-4

Estimated number of researchers, selected region or country: 2000–15



EU = European Union.

Note(s)

Data are not available for all regions or countries for all years. Researchers are full-time equivalents. Counts for China before 2009 are not consistent with Organisation for Economic Co-operation and Development (OECD) standards. Counts for South Korea before 2007 exclude social sciences and humanities researchers.

Source(s)

OECD, Main Science and Technology Indicators (2017/1), https://www.oecd.org/sti/msti.htm.

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The worldwide total of workers engaged in research has been growing rapidly, and growth has been more robust in parts of Asia. The most rapid expansion has occurred in South Korea, which nearly doubled its number of researchers between 2000 and 2006 and continued to grow strongly thereafter, and in China, which reported more than twice the number of researchers in 2008 compared with 2000 and likewise reported substantial growth in later years. (China's pre-2009 data are not comparable to China's data for 2009 onward.) The United States and the EU experienced steady growth at lower rates. Exceptions to the worldwide trend included Japan (which remained relatively flat) and Russia (which experienced a decline).

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[1] An additional complexity, as data from the United States show, is that a direct correlation often does not exist between an individual's degree and occupation. S&E degree holders report applying their S&E expertise in a wide variety of jobs, including

S&E and non-S&E jobs. This indicates that the application of S&E knowledge and skills is widespread across the technologically sophisticated U.S. economy and is not just limited to jobs classified as S&E. For more information on this and the U.S. S&E workforce, see National Science Board (2015).

R&D Expenditures and R&D Intensity

The rising number of researchers and expanding S&E education have been accompanied by strong and widespread growth in R&D expenditures. The worldwide estimated total of R&D expenditures continued to rise at a substantial pace, more than doubling over the 15-year period between 2000 and 2015, indicative of the global trends toward investments in knowledge and technology.

Global R&D activity continues to be concentrated in North America, Europe, and the East and Southeast Asia and South Asia regions (Figure O-5). Among individual countries, the United States is by far the largest R&D performer, followed by China—whose R&D spending exceeded that of the EU total—and Japan (Figure O-6). Together, the United States, China, and Japan accounted for over half of the estimated $1.9 trillion in global R&D in 2015. Germany is fourth, at 6%. South Korea, France, India, and the United Kingdom make up the next tier of performers—each accounting for 2%–4% of the global R&D total.

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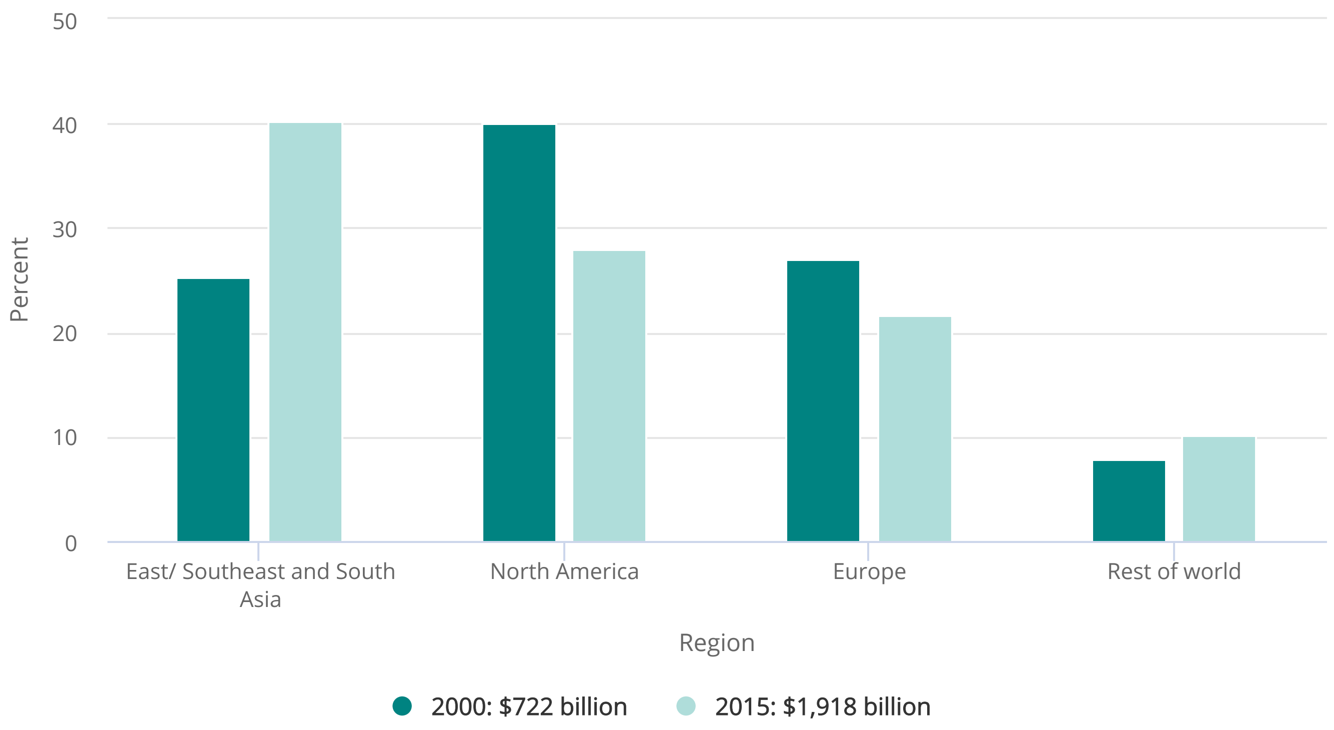
FIGURE O-5

Regional share of worldwide R&D expenditures: 2000 and 2015



Note(s)

East/Southeast and South Asia includes China, Taiwan, Japan, South Korea, Singapore, Malaysia, Thailand, Indonesia, Philippines, Vietnam, India, Pakistan, Nepal, and Sri Lanka.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics estimates, August 2017. Based on data from the Organisation for Economic Co-operation and Development, Main Science and Technology Indicators (2017/1), and the United Nations Educational, Scientific and Cultural Organization (UNESCO), Institute for Statistics database, data.uis.unesco.org.

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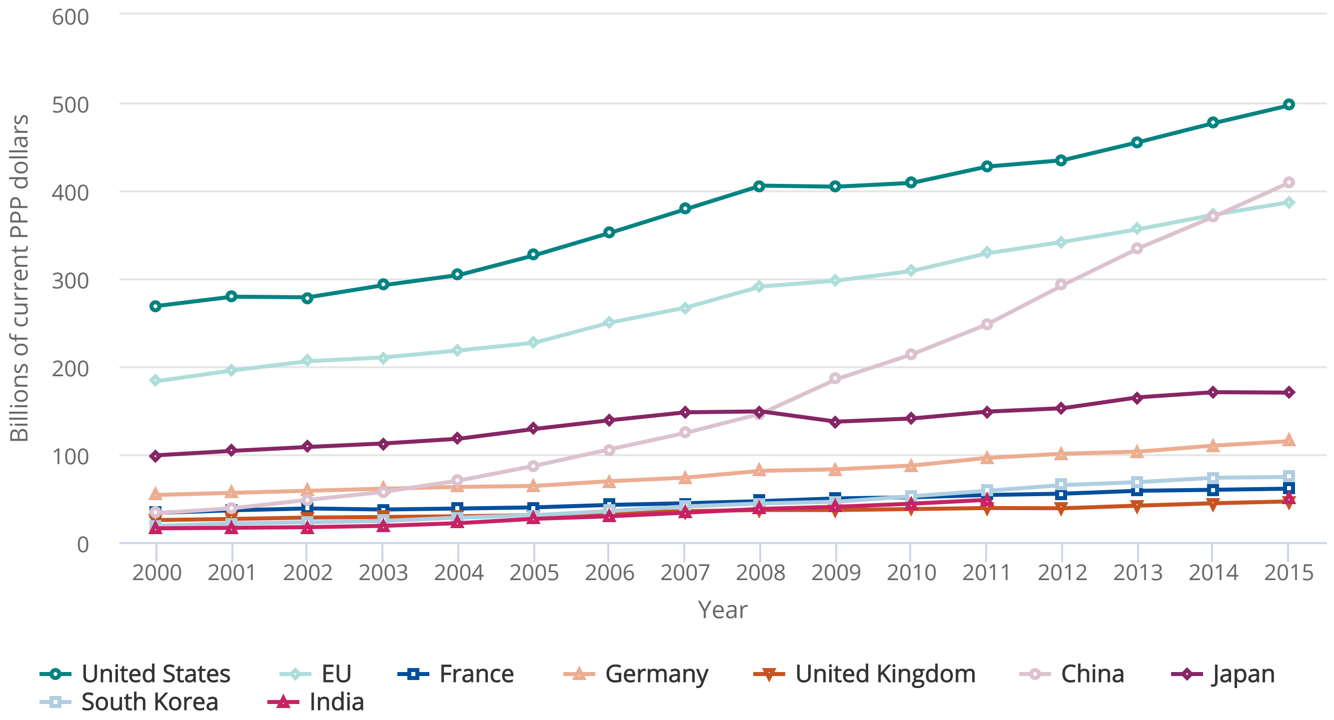
FIGURE O-6

Gross domestic expenditures on R&D, by selected region, country, or economy: 2000–15



EU = European Union; PPP = purchasing power parity.

Note(s)

Data are for the top eight R&D-performing countries and the entire EU. Data are not available for all countries for all years. Data for the United States in this figure reflect international standards for calculating gross expenditures on R&D, which vary slightly from the National Science Foundation's protocol for tallying U.S. total R&D.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Patterns of R&D Resources (annual series); Organisation for Economic Co-operation and Development, Main Science and Technology Indicators (2017/1); United Nations Educational, Scientific and Cultural Organization (UNESCO), Institute for Statistics database, data.uis.unesco.org, accessed 13 October 2017. See Appendix Table 4-12.

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A notable trend over the past decade has been the growth in R&D spending in the regions of East and Southeast Asia and South Asia compared to the other major R&D-performing areas. China continues to display the most vigorous R&D growth, accounting for nearly one-third of the global increase in R&D spending over the 2000–15 period. Despite growth in nominal spending on R&D, differences in growth rates across the world led both the United States and Europe to experience substantial declines in their shares of global R&D (from 37% to 26% in the United States and from 27% to 22% in Europe between 2000 and 2015). During the same period, the economies of East and Southeast Asia—including China, Japan,

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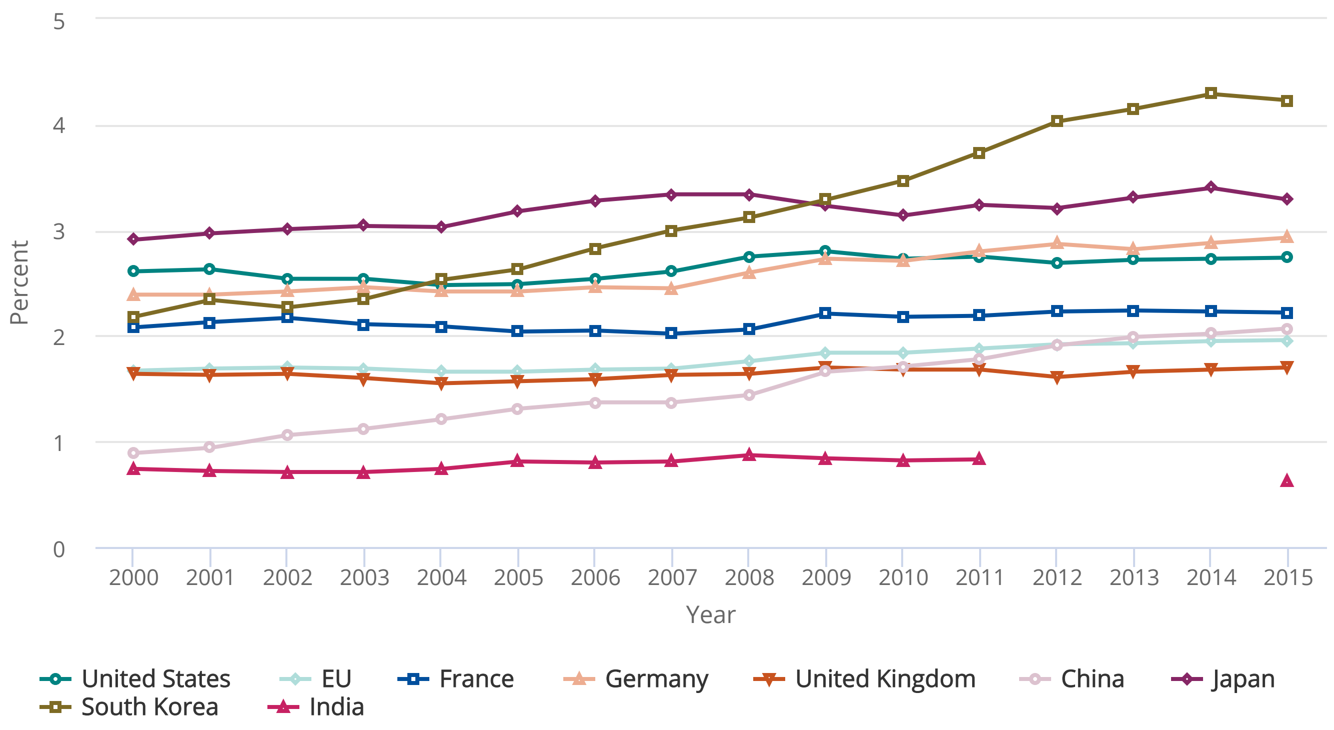
Malaysia, Singapore, South Korea, Taiwan, and India—saw an increase in their combined global share from 25% to 40%, thus exceeding the respective U.S. and the European R&D shares in 2015.

Countries and economies, however, vary in their R&D intensity, their relative focus on early versus later stages of R&D, and funding sources (business versus government sectors). Along with total R&D spending, the share of such spending relative to the size of the total economy is seen as a useful indicator of innovative capacity. Although the United States invests far more in R&D than any other individual country, several other, smaller economies have greater *R&D intensity*—that is, a higher ratio of R&D expenditures to gross domestic product (GDP). A stated goal by the EU is to achieve a 3% R&D-to-GDP ratio, one of the five targets for the EU in 2020 (EC 2010). In 2015, the United States had an R&D intensity of 2.7% (📊Figure O-7). Israel (not shown) and South Korea are essentially tied for the top spot, with ratios of 4.3% and 4.2%, respectively. Over the past decade, the ratio has fluctuated within a relatively narrow range in the United States, although the U.S. rank in this indicator has been slowly falling in recent years: 8th in 2009, 10th in 2011, and 11th in 2013 and 2015. Over the past decade, R&D intensity rose gradually in the EU as a whole; in South Korea and particularly in China, which started with a low base, the R&D-to-GDP ratio rose significantly in the last 10 years.

FIGURE O-7

R&D intensity, by selected region, country, or economy: 2000–15



EU = European Union.

Note(s)

Data reflect gross domestic R&D expenditures as a share of gross domestic product. Data are for the top eight R&D-performing countries and the entire EU. Data are not available for all countries for all years. Data for the United States in this figure reflect international standards for calculating gross expenditures on R&D, which vary slightly from the National Science Foundation's protocol for tallying U.S. total R&D.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Patterns of R&D Resources (annual series); Organisation for Economic Co-operation and Development, Main Science and Technology Indicators (2017/1); United Nations Educational, Scientific and Cultural Organization (UNESCO), Institute for Statistics database, data.uis.unesco.org, accessed 13 October 2017. See Appendix Table 4-12.

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Many governments have only limited direct control over achieving a targeted R&D-to-GDP ratio because businesses are the predominant source of R&D funding in many leading R&D-performing nations. Businesses in the United States funded about 62% of all U.S. R&D in 2015. The corresponding business sector shares are higher, around 66%–78% in Germany, China, South Korea, and Japan, and are lower in France (56%) and the United Kingdom (48%). R&D funded by the government sector, the second major source of R&D funding in many countries, accounted for about 26% of the U.S. national total; for 24%–35% in South Korea, the United Kingdom, Germany, and France; for 21% in China; and for 15% in Japan.[1]

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In the United States, the federal government is a major source of R&D funding for universities, nonprofit organizations, federal institutions, and federally funded research and development centers (FFRDCs). The federal government funds a substantial amount of all basic (accounting for 44% of funding in 2015) and applied research (accounting for about 36% of funding in 2015). During the post-recession period from 2010 through 2015, however, the share of U.S. R&D funded by the federal government declined, from just over 30% to around one-fourth, primarily reflecting the waning after 2010 of the incremental funding from the American Recovery and Reinvestment Act (ARRA) and the uncertain federal budget environment since 2011, including broad federal spending caps. Business R&D has led the overall growth in U.S. R&D during this period. The decline in federal funding is an important trend that we will continue to follow, given the federal government's critical role in the overall R&D infrastructure in the United States.

Countries also vary in their relative focus on basic research, applied research, and experimental development.[2] China spends only about 5% of its R&D funds, compared to 17% in the United States, on *basic research*—work aimed at gaining comprehensive knowledge or understanding of the subject under study without specific applications in mind. However, this still amounted to about $21 billion of basic research performance in China in 2015, more than France ($15 billion) which has a relatively large focus on basic research (24% of annual R&D). On the contrary, China spends 84% of its R&D funds, compared to 64% in the United States, on *experimental development*—work directed towards the production of useful materials, devices, systems, or methods, including the design and development of prototypes and processes. The lack of specific applications as a goal introduces an element of risk and uncertainty in basic research, which is why a substantial amount of basic research is typically funded by the government. China's more-limited focus on basic research may reflect the large business sector role in R&D funding as well as the opportunity to build on basic research done elsewhere (Qui 2014).

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[1] Business spending and government spending as reported here are defined by international guidance. As recommended in the *Frascati Manual 2015* (OECD 2015), R&D funding from government-run businesses is to be reported as funding from the business sector. Actual sector classification may differ somewhat by the circumstances in specific countries.

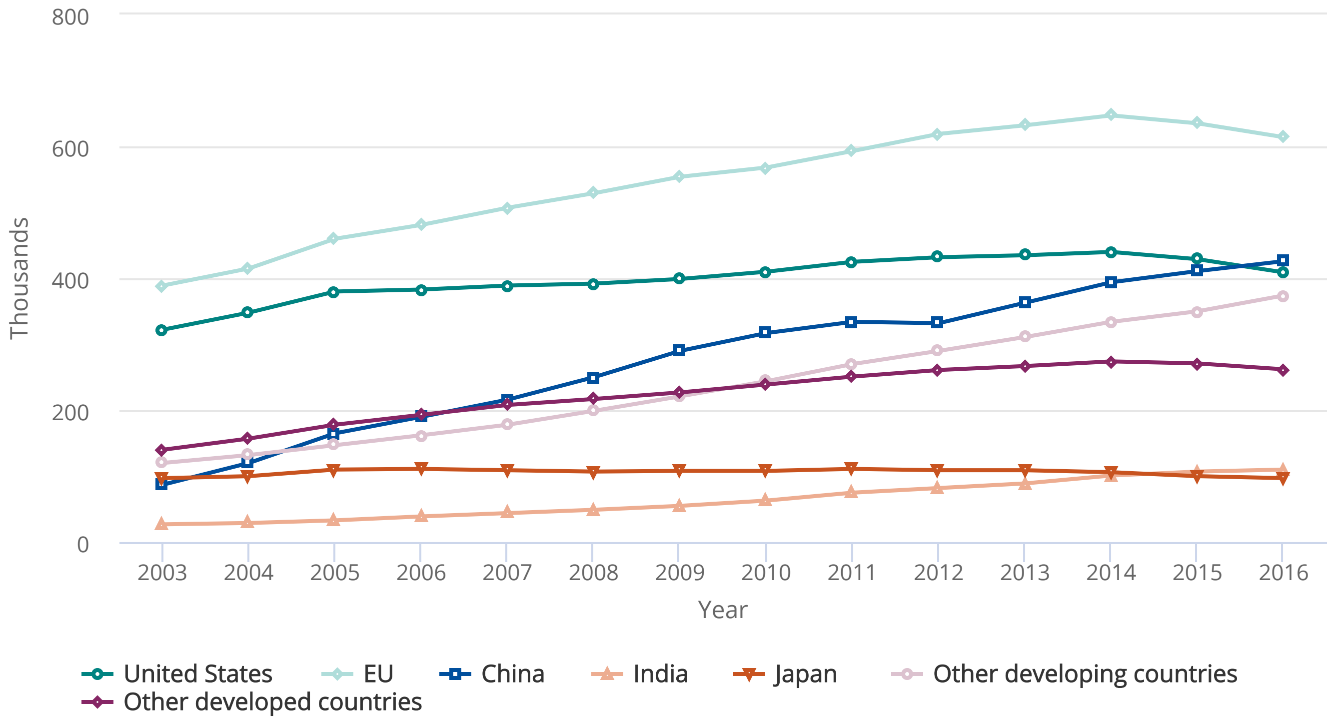
[2] These terms are defined in the chapter Glossary.

Research Publications

Research produces new knowledge; refereed S&E publications are one of the tangible measures of research activity that have been broadly available for international comparison. The United States, the EU, and the developed world[1] produce the majority of refereed S&E publications. However, similar to the trends for researchers and for R&D spending, S&E research output in recent years has grown more rapidly in China and other developing countries when compared with the output of the United States and other developed countries. China's S&E publication output rose nearly fivefold since 2003, and as a result, China's output, in terms of absolute quantity, is now comparable to that of the United States (Figure O-8). Research output has also grown rapidly in other developing countries—particularly, Brazil (not shown) and India.

FIGURE O-8

S&E articles, by selected region, country, or economy: 2003–16



EU = European Union.

Note(s)

Article counts refer to publications from a selection of journals, books, and conference proceedings in S&E from Scopus. Articles are classified by their year of publication and are assigned to a region, country, or economy on the basis of the institutional address(es) listed in the article. Articles are credited on a fractional-count basis. The sum of the regions, countries, or economies may not add to the world total because of rounding. Some publications have incomplete address information for coauthored publications in the Scopus database. The unassigned category count is the sum of fractional counts for publications that cannot be assigned to a region, country, or economy. See Appendix Table 5-27.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; Elsevier, Scopus abstract and citation database (https://www.scopus.com/), accessed July 2017. For more information on the International Monetary Fund economic classification of countries, see https://www.imf.org/external/pubs/ft/weo/2016/01/weodata/groups.htm, accessed December 2016.

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The subject-matter emphasis of scientific research varies somewhat across countries and regions. Biomedical sciences (biological sciences, medical sciences, and other life sciences) and engineering—two fields that are vital to knowledge-intensive and technologically advanced economies—account for 57% of the worldwide total of S&E publications. In 2016, the United States and the EU produced significant numbers of global biomedical sciences articles, each larger than China's production. However, China produced the largest number of engineering articles, surpassing the output of both the United States and the EU.

When researchers in one country cite the published work of researchers in another country, the resulting citation patterns are an indication of knowledge flows across regions. These patterns are strongly influenced by cultural, geographic, and language ties as well as perceived impact; for example, researchers are more likely to cite work written in their native language. U.S. articles disproportionately cite publications by Canadian and United Kingdom authors. In comparison, U.S. authors cite Chinese, Indian, and other Asian publications less than would be expected based on the overall publication output of these places.

Language factors notwithstanding, citations to refereed articles and presentations are an oft-used indicator of the use and impact of research output, and U.S. publications receive the largest number of citations. Adjusting for the size of each country's research pool, researchers based in the United States, Canada, Switzerland, and several countries of northern Europe (Denmark, Finland, Iceland, the Netherlands, Norway, Sweden, and the United Kingdom) set the bar with respect to the production of influential research results. One measure of the influence of a region's research is its share of the world's top 1% of cited articles compared to what would be expected based on the size of each country's pool of S&E publications. With this measure, if a country's share is exactly what would be expected based on its publication output, the percentage is 1.0%. The U.S. percentage has held steady, at about twice the expected value (1.8%–1.9%), while the percentage of articles from the EU in the top 1% grew from 1.0% to 1.3% between 2000 and 2014 (Figure O-9). China's share of this top 1%, starting from a low base, more than doubled in the same period, from 0.4% to 1.0%.[2]

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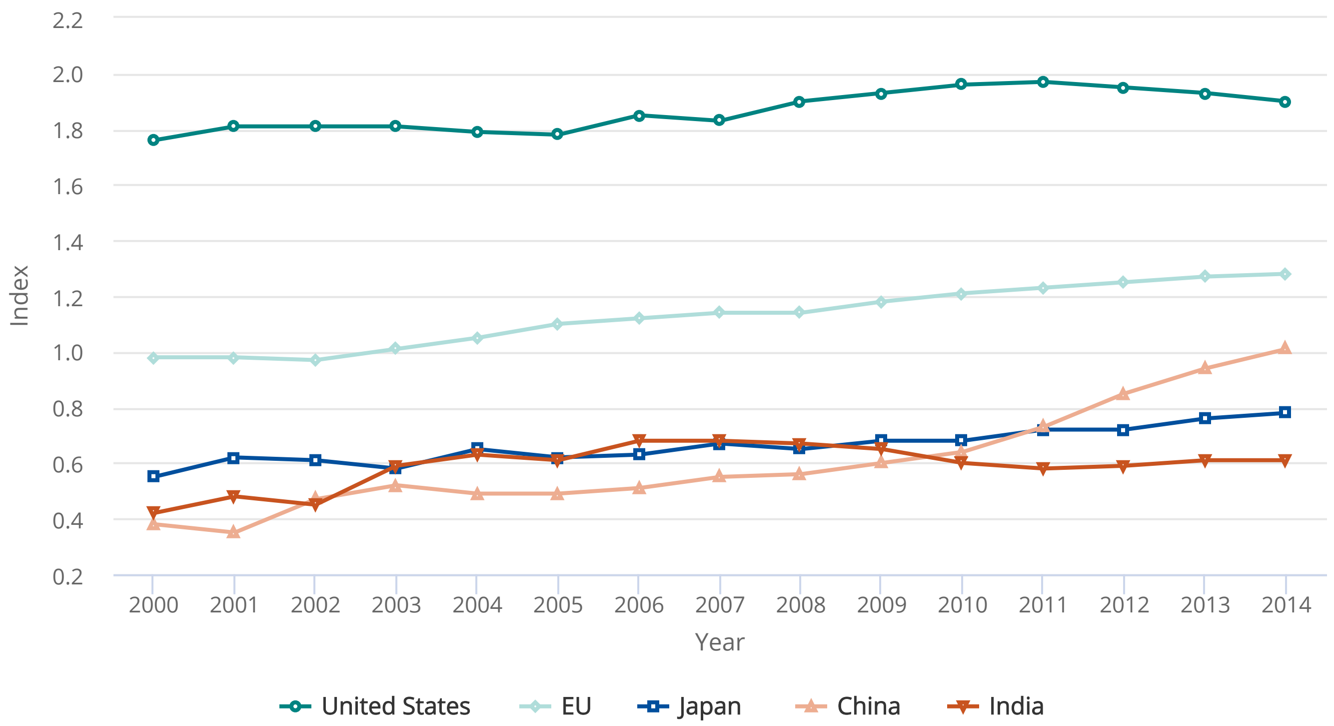
FIGURE O-9

S&E publication output in the top 1% of cited publications, by selected region, country, or economy: 2000–14



EU = European Union.

Note(s)

An index of 1.00 indicates that articles are cited at their expected level. An index of 2.00 indicates that articles are cited at twice their expected level. The index measures the share of publications that are in the top 1% of the world's cited publications, relative to all the country's publications in that period and field. It is computed as follows: $Sx = HCPx/Px$, where Sx is the share of output from country x in the top 1% most-cited articles; $HCPx$ is the number of articles from country x that are among the top 1% most-cited articles in the world; and Px is the total number of papers from country x in the database that were published in 2014 or earlier. Citations are presented for the year of publication, showing the counts of subsequent citations from peer-reviewed literature. At least 2 years of data after publication are needed for a meaningful measure. Publications that cannot be classified by country or field are excluded. Articles are classified by the publication year and assigned to a region, country, or economy on the basis of the institutional address(es) listed in the article. The world average stands at 1.00% for each period and field. See Appendix Table 5-26 and Appendix Table 5-51.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; Elsevier, Scopus abstract and citation database (https://www.scopus.com/), accessed July 2017.

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Collaboration on S&E publications between authors of different countries has risen over time, reflecting both an increased pool of trained researchers and improvements in communications technologies. Other drivers include budget pressures on R&D spending that increase the incentives for collaboration and sharing resources and also on the need to coordinate globally on challenges like climate change, infectious diseases, and the allocation of scarce natural resources (Wagner, Park, and Leydesdorff 2015).

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[1] For more information on the developing and developed economy classification, see the International Monetary Fund classification of countries, available at https://www.imf.org/external/pubs/ft/weo/2017/02/weodata/groups.htm, accessed 4 December 2017. According to the IMF, "This classification is not based on strict criteria, economic or otherwise, but instead has evolved over time with the objective of facilitating analysis by providing a reasonably meaningful organization of the data."

[2] The implications of these differences in top citations should be drawn with care because the data used for the analysis require that article abstracts be provided in the English language. Many publications from China have English-language abstracts but Chinese-language text, limiting their accessibility and likelihood of citation for researchers not fluent in Chinese.

Invention, Knowledge Transfer, and Innovation

S&E research and the S&T knowledge produced thereby are an important part of the overall innovation process (Pavitt 2005). These activities contribute to a nation's capacity for innovation. The potential to transform this capacity into implementation and economic growth drives interest in internationally comparable measures of innovation. Chapter 8 describes innovation as an interrelated system that translates the creativity and knowledge from S&E activities into benefits to society and the economy. Discoveries and inventions evolve from potential to realized usefulness through the interaction of a wide variety of actors and institutions. These take place through interrelated activities: *invention* is the process of bringing something new and potentially useful into being; *knowledge transfer* involves the transfer of S&T to and from businesses, government entities, academe, and other organizations and to individuals for further development and eventual commercial and otherwise useful applications; and *innovation* takes place when a new or significantly improved product or process, including in business practices, workplace organization or external relations, is implemented.

Science and Engineering Indicators 2018 presents detailed data on these various components for the United States, but internationally comparable data on these topics are limited. The Overview presents selected topics from this three-part system for which comprehensive and comparable international data are available. Two such topics are patents, an important (albeit partial) indicator of invention, and venture capital, an important catalyst for the transformation of inventions into innovation and practical use.

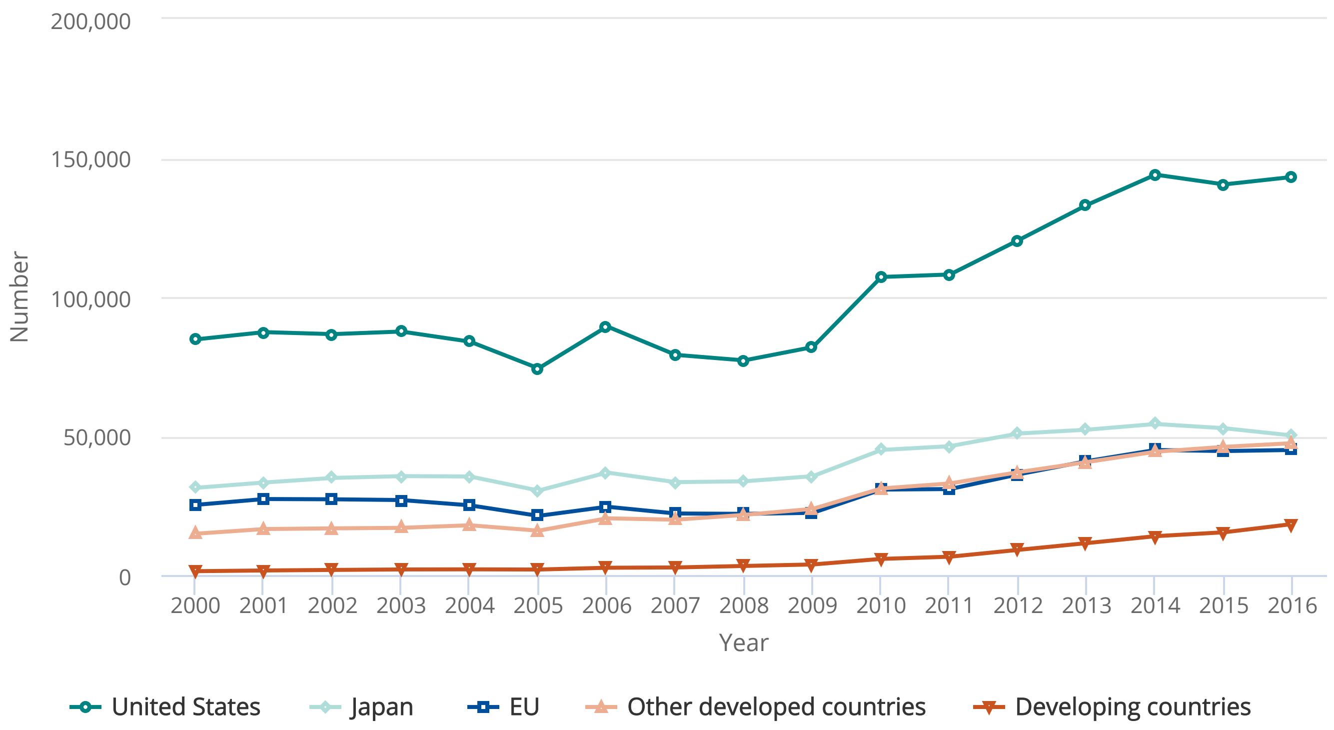
Patenting confers the rights of property to novel, useful, and nonobvious inventions for a specified period. Although the propensity to patent varies across technology areas—and many patents do not become commercialized or lead to practical innovations—patent grants and applications are one indicator of invention. While academic studies question the strength of the link between patents and innovation, strengthening of intellectual property protection has been found to promote foreign investment, which may in turn provide a pathway for knowledge flows (Boldrin and Levine 2013).

The developed world dominates global patenting, with notable growth (albeit from low bases) in several Asian economies. The U.S. Patent and Trademark Office (USPTO) grants patents to inventors worldwide, with over 300,000 patents granted in 2016. Inventors from the United States, Japan, and EU account for the majority of USPTO patents (Figure O-10). In comparison however, patents granted to inventors from the rest of the world have risen more robustly since 2000, with more than a three-fold increase in patents to other developed economies and a more than 13-fold increase in patents to developing economies. The U.S. share of USPTO patents declined to under half of all USPTO patents by 2008.

Overview of the State of the U.S. S&E Enterprise in a Global Context

FIGURE O-10

USPTO patents granted, by selected region, country, or economy of inventor: 2000–16



EU = European Union; USPTO = U.S. Patent and Trademark Office.

Note(s)

Patent grants are fractionally allocated among regions, countries, or economies based on the proportion of the residences of all named inventors.

Source(s)

Science-Metrix; SRI International. See Appendix Table 8-4.

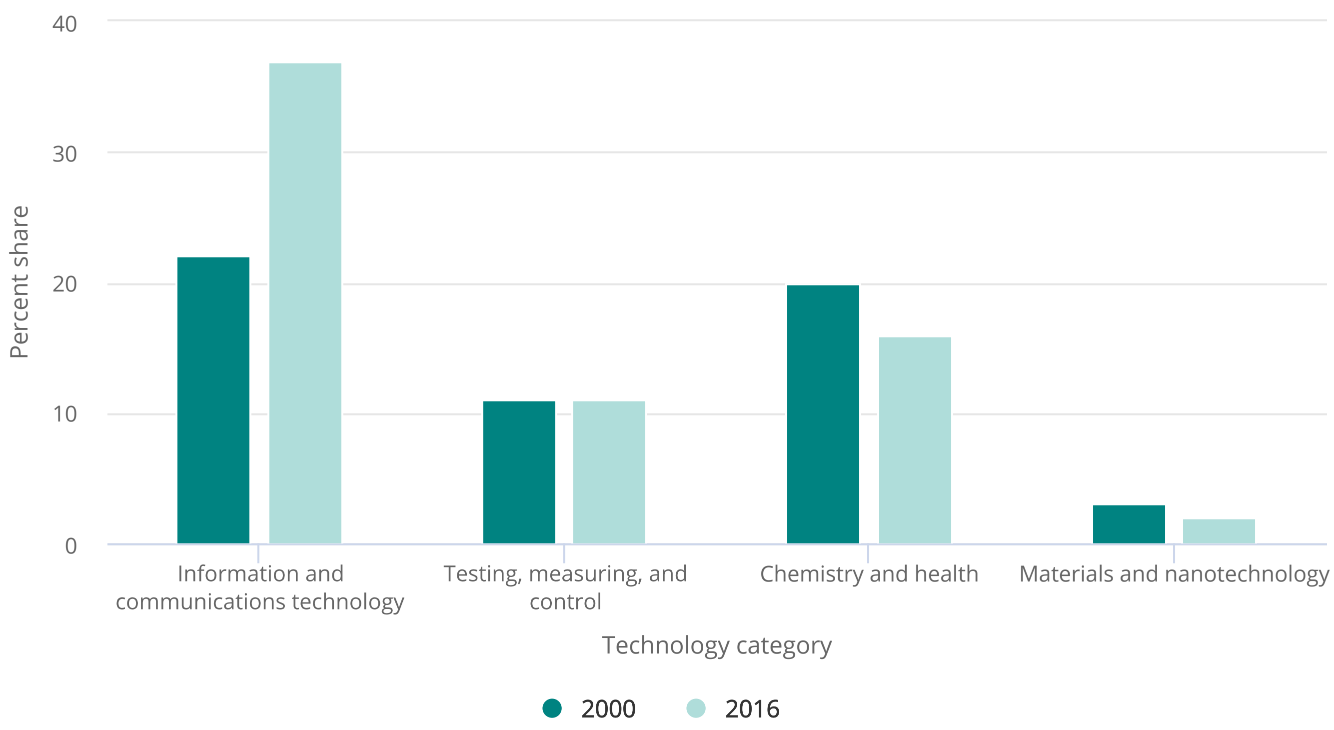
Science and Engineering Indicators 2018

U.S. patents to inventors from developing countries have risen from under 1% in 2000 to 6% in 2016, with China (4%) and India (1%) accounting for the bulk of these patents. China and India, however, still receive relatively modest shares of USPTO patents. Additionally, China's patent office has experienced a much faster growth in patent applications than in the USPTO and other major patent offices (WIPO 2014). Unlike USPTO patents, utility patents in China are not subject to extensive examination, and while the foreign share is growing, patents in China's patent office are overwhelmingly filed by residents of China (Hu 2010).

Three broad technology categories closely linked to the knowledge- and technology-intensive (KTI) industries (discussed in the next section) account for more than 60 percent of USPTO patents granted in 2016: information and communications technologies (ICT);[1] testing, measuring, and control;[2] and chemistry and health.[3] Materials and nanotechnology,[4] also linked to KTI industries, accounted for 2% of USPTO patents in 2016. Between 2000 and 2016, the technology focus of USPTO patents granted has shifted toward more ICT-related inventions (which rose from 22% of the total in 2000 to 37% of the total in 2016) and slightly fewer chemistry and health-related ones (share fell from 20% to 16% from 2000 to 2016) (Figure O-11).

FIGURE O-11

USPTO patents granted in selected broad technology categories: 2000 and 2016



USPTO = U.S. Patent and Trademark Office.

Note(s)

Data refer to the share of all USPTO patents in a particular technology category in the specified year. Patents are allocated according to patent inventorship information. Patents are classified under the World Intellectual Property Organization classification of patents, which classifies International Patent Classification codes under 35 technical fields. Fractional counts of patents were assigned to each technological field on patents to assign the proper weight of a patent to the corresponding technological fields under the classification. Patents are fractionally allocated among regions, countries, or economies based on the proportion of residences of all named inventors. Data were extracted in April 2017.

Source(s)

Science-Metrix; PatentsView; SRI International. See Appendix Table 8-5 through Appendix Table 8-17 for supporting data and Table 8-2 for definitions of the broad technology categories.

Science and Engineering Indicators 2018

The pattern of specialized concentration at the country level, previously noted in a variety of indicators, is also evident in patenting: each economy or country's patents reflect different strengths. Adjusting for the size of its patenting pool, USPTO

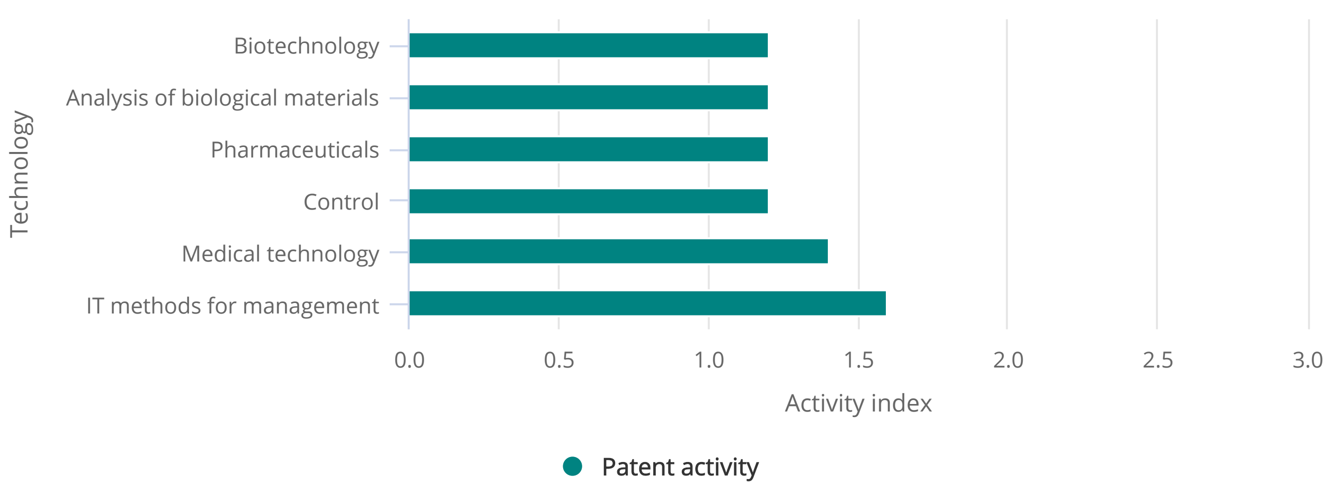
Overview of the State of the U.S. S&E Enterprise in a Global Context

patents awarded to U.S. inventors have a particularly high concentration in the ICT area of information technology (IT) methods for management, a field that includes special-purpose software for business management. This U.S. specialization in part reflects patent rule differences within each country. In many countries outside of the United States, business methods software is not patentable (Schmoch 2008). Both U.S. and EU inventors are particularly concentrated in the testing, measuring, and control area, such as analysis of biological materials, and in chemistry and health, such as biotechnology and pharmaceuticals. In contrast with EU inventors, Japanese inventors with USPTO patents focus in the ICT area of semiconductors (Figure O-12).

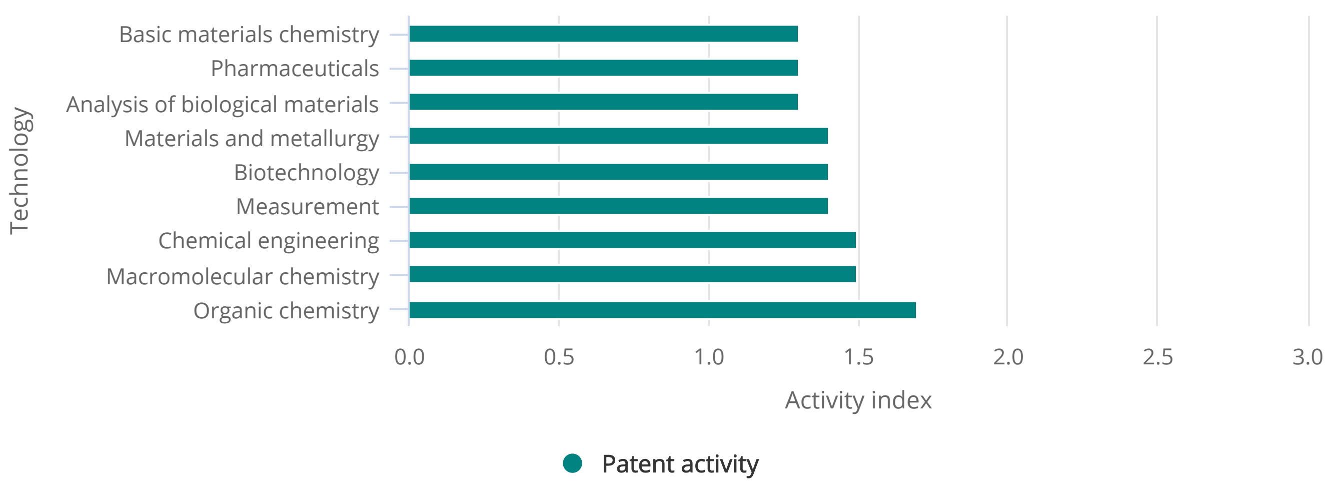
FIGURE O-12

Patent activity index for selected technologies for the United States, EU, and Japan: 2014–16

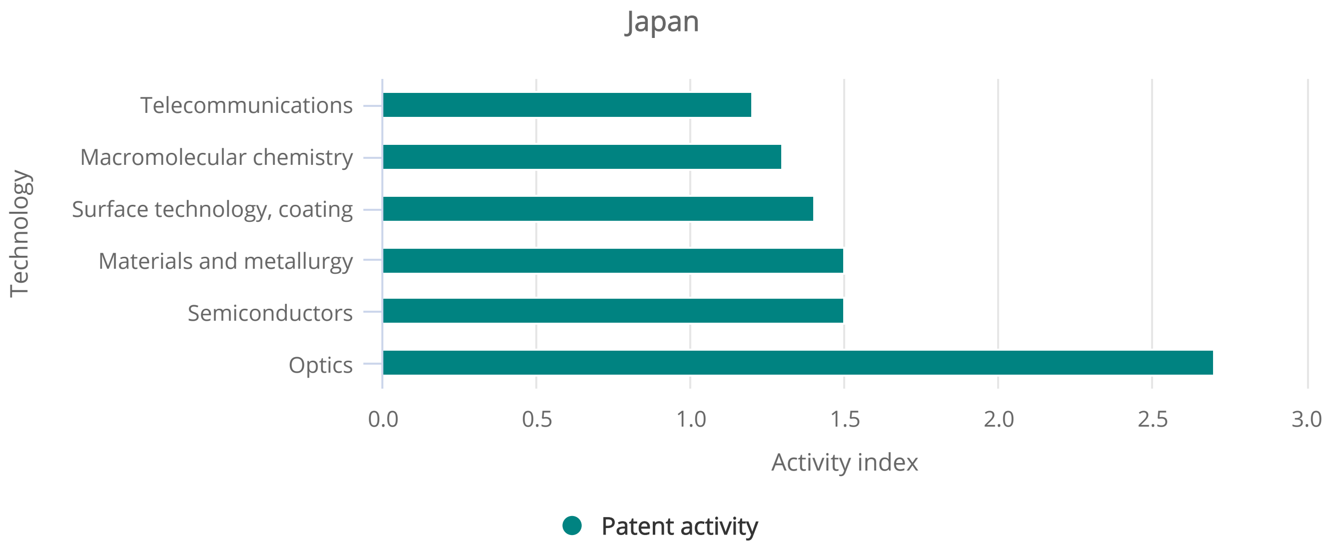
United States



EU



Overview of the State of the U.S. S&E Enterprise in a Global Context



EU = European Union; IT = information technology.

Note(s)

A patent activity index is the ratio of a country's share of a technology area to its share of all patents. A patent activity index greater (less) than 1.0 indicates that the country is relatively more (less) active in the technology area. Patents are classified under the World Intellectual Property Organization classification of patents, which classifies International Patent Classification codes under 35 technical fields. Fractional counts of patents were assigned to each technological field on patents to assign the proper weight of a patent to the corresponding technological fields under the classification. Patents are fractionally allocated among regions, countries, or economies based on the proportion of residences of all named inventors. Data were extracted in April 2017.

Source(s)

Science-Metrix; PatentsView; SRI International.

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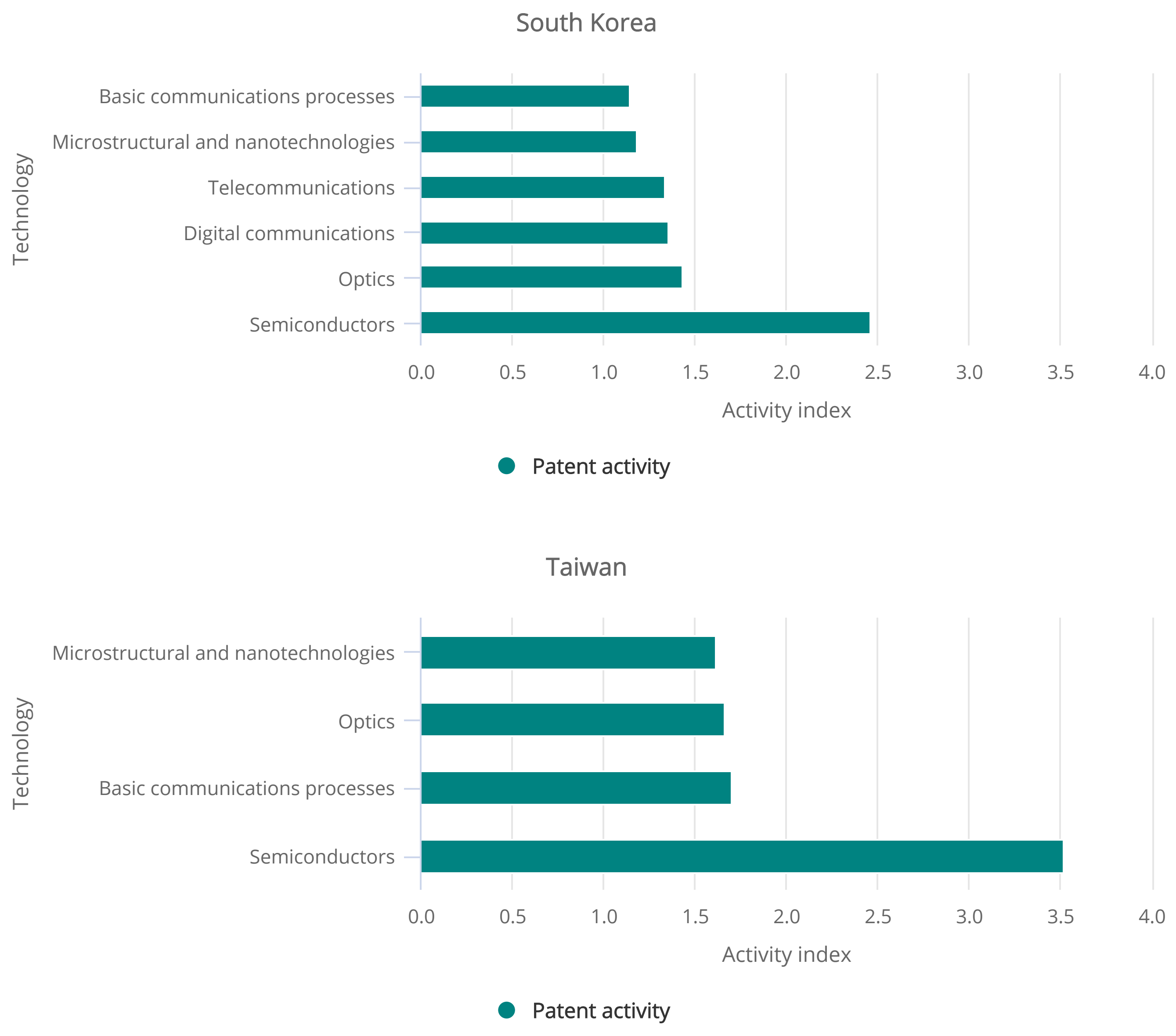
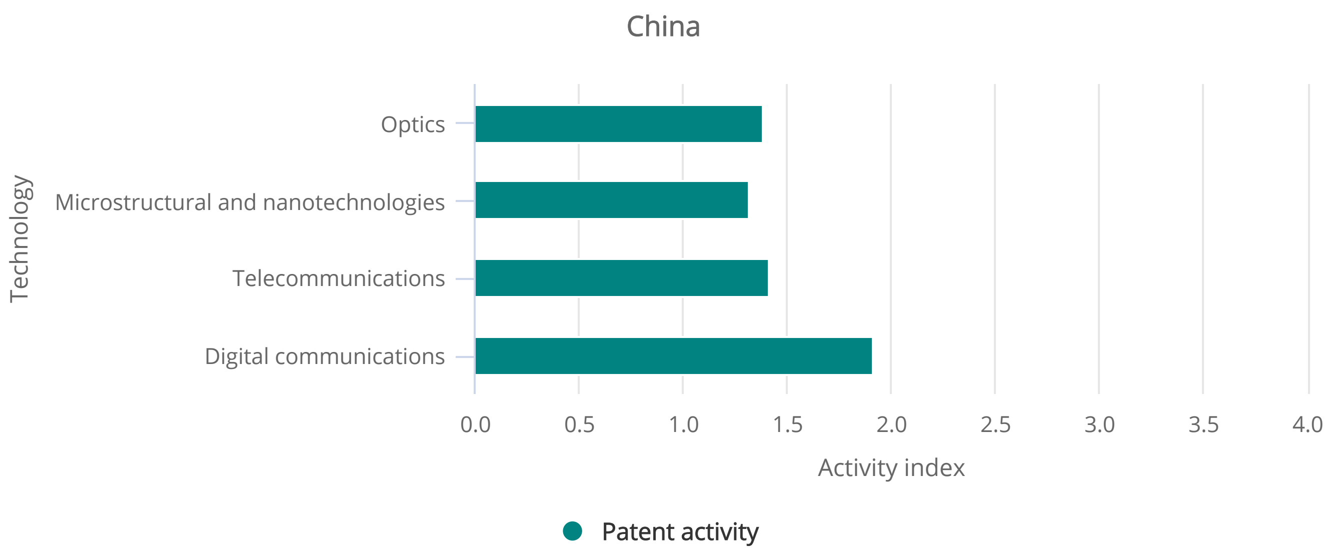
Inventors in Japan, South Korea, Taiwan, and China are focused in ICT technologies—these technologies include basic communication processes, semiconductors, and telecommunications. These four Asian economies also have a focus in optics, a technology in the testing, measuring, and control area category that includes lasers as well as optical switching. Japanese inventors are more than twice as likely to be granted USPTO patents in optics compared to other fields. South Korea, Taiwan, and China also focus on nanotechnologies (Figure O-12 and Figure O-13).

FIGURE O-13

Patent activity index of selected technologies for South Korea, Taiwan, and China: 2014–16





Note(s)

A patent activity index is the ratio of a country's share of a technology area to its share of all patents. A patent activity index greater (less) than 1.0 indicates that the country is relatively more (less) active in the technology area. Patents are classified under the World Intellectual Property Organization classification of patents, which classifies International Patent Classification codes under 35 technical fields. Fractional counts of patents were assigned to each technological field on patents to assign the proper weight of a patent to the corresponding technological fields under the classification. Patents are fractionally allocated among regions, countries, or economies based on the proportion of residences of all named inventors. Data were extracted in April 2017.

Source(s)

Science-Metrix; PatentsView; SRI International.

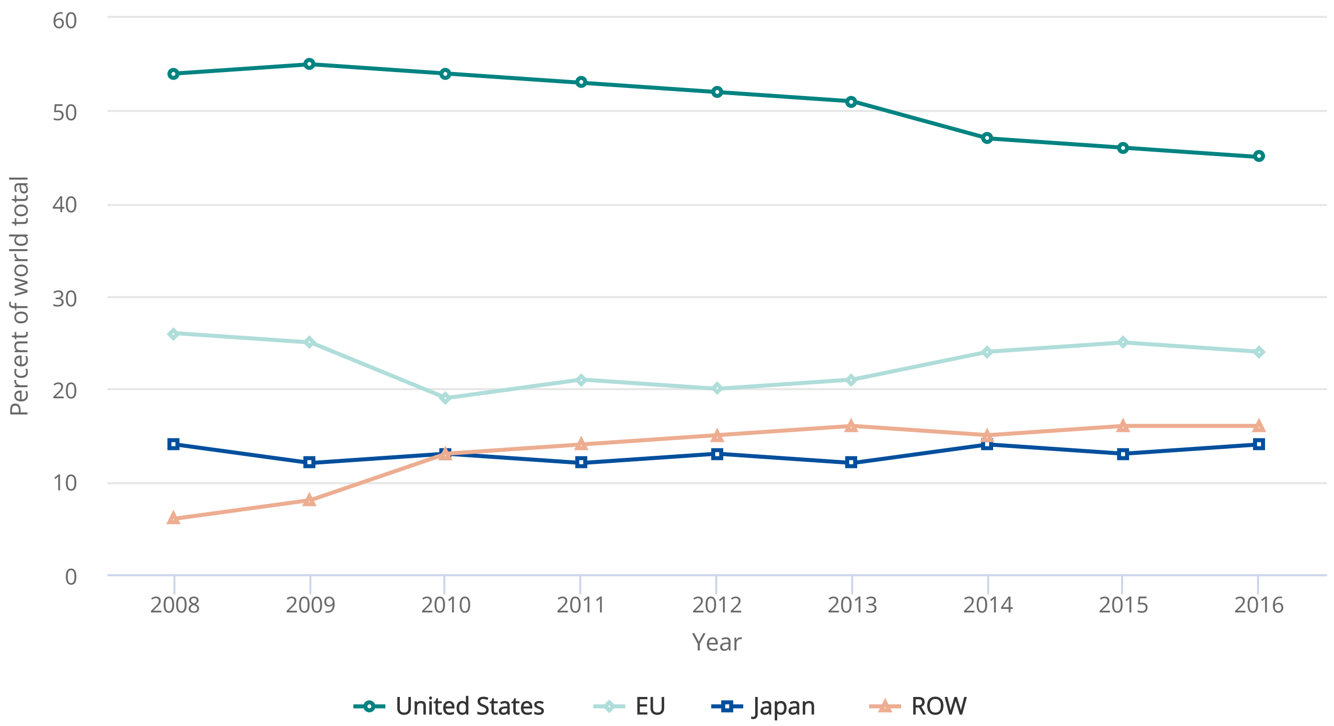
Science and Engineering Indicators 2018

Knowledge transfer, including the transfer and dissemination of technology from inventors to users, is a critical component of the innovation system. International transactions allow tracking of the market-based diffusion of technology and innovation across international boundaries. One measure of such international transaction is the export flows of intellectual property, measured by charges for the use on intellectual property, including cross-border royalties and fees collected for licensing proprietary technologies.[5] Although trade patterns in royalties and licensing fees are affected by different tax treatments, income from intellectual property broadly indicates which nations are producing intellectual property products with commercial value. These patterns generally correspond to the countries and economies holding patents. Not surprisingly, export revenue from the use of intellectual property continues to be concentrated in the lead recipients of USPTO patents: the United States, the EU, and Japan. U.S. export revenue for use of intellectual property was $122 billion in 2016; in that same year, it was $66 billion for the EU and $39 billion for Japan. However, the share accounted for by the United States has declined, and the rest of the world's share (excluding the EU and Japan) more than doubled from 6% to 16% between 2008 and 2016 (Figure O-14). As the U.S., EU, and Japan export revenues for use of intellectual property have leveled off or declined in the last few years, these revenues have continued to grow in other countries and regions.

Overview of the State of the U.S. S&E Enterprise in a Global Context

FIGURE O-14

Exports of intellectual property (charges for their use), by selected region, country, or economy: 2008–16



EU = European Union; ROW = rest of world.

Note(s)

EU exports do not include intra-EU exports.

Source(s)

World Trade Organization, Trade and tariff data, https://www.wto.org/english/res_e/statis_e/statis_e.htm, accessed 15 August 2017. See Appendix Table 8-29.

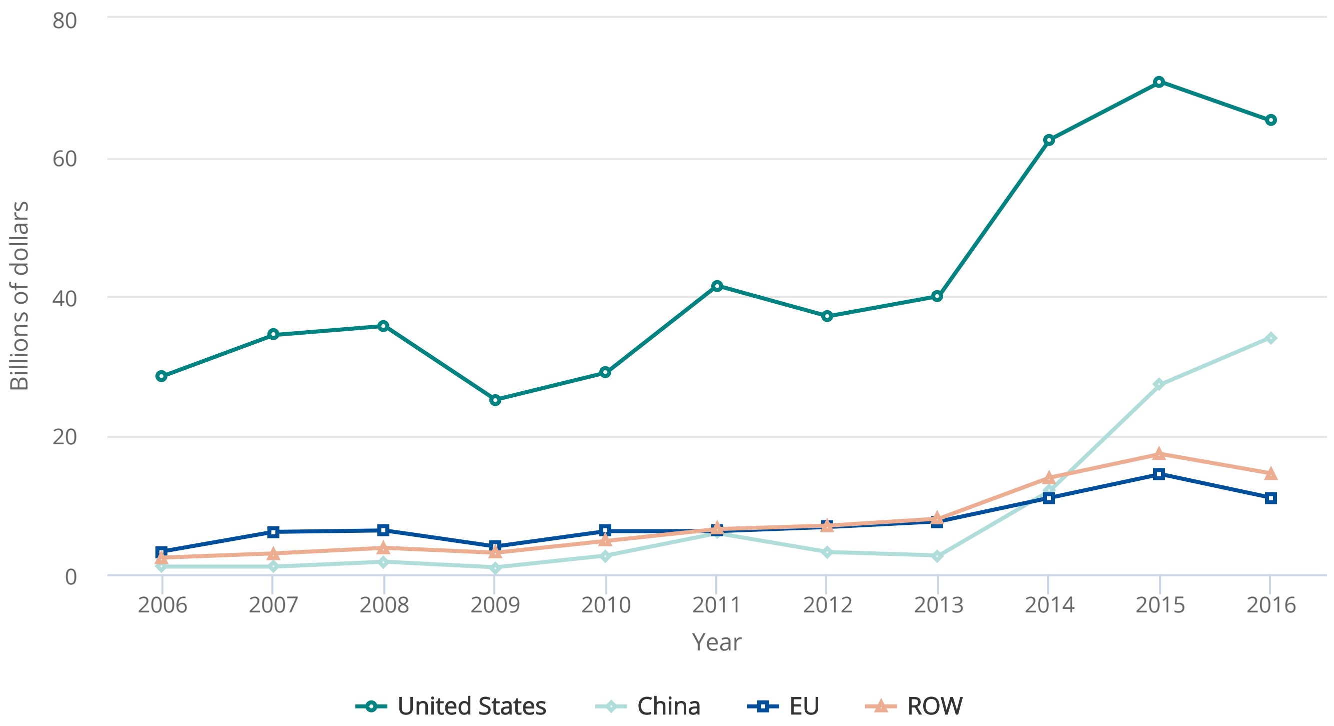
Science and Engineering Indicators 2018

Another essential component of the translation of inventions into innovations and practical use is access to financing. Developing and commercializing new and emerging technology is inherently risky, and financial support can provide insurance against some of this uncertainty. Venture capital investment is an indicator of support for emerging technologies that have the potential for successful commercialization and was globally about $131 billion in 2016. The United States attracts slightly more than half of this venture capital funding, although its share has been declining as other countries, particularly China, ramp up their S&T capabilities for developing new technologies.

Seed-stage venture capital refers to very early-stage financing, which generally provides funding for preliminary business operations, such as proof-of-concept development and initial product development, as well as marketing for startups and small firms that are developing new technologies. The United States attracted more than half of the nearly $6 billion of global seed-stage venture capital investment in 2016. These seed-stage investments are very small relative to early- and later-stage venture capital investment (totaling almost $125 billion in 2016), which provide financing for further development, production, commercialization, and marketing of new technologies (Figure O-15 shows the data for the combined category of early- and later-stage venture capital). The United States attracts slightly more than half of the global early- and later-stage venture capital investment, followed by China. Between 2010 and 2016, the level of investment grew strongly in the U.S. although the U.S. global share dropped from 68% to 52%. In China, investment rose from a low base between 2006 and 2013; after 2013, growth accelerated as investment leaped from almost $3 billion in 2013 to $34 billion in 2016 (Figure O-15), resulting in its global share to rise from 5% to 27%.

FIGURE O-15

Early- and later-stage venture capital investment, by selected region, country, or economy: 2006–16



EU = European Union; ROW = rest of world.

Note(s)

Early-stage financing supports product development and marketing, the initiation of commercial manufacturing, and sales; it also supports company expansion and provides financing to prepare for an initial public offering. Later-stage financing includes acquisition financing and management and leveraged buyouts.

Source(s)

PitchBook, Venture capital and private equity database, https://my.pitchbook.com/.

Science and Engineering Indicators 2018

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[1] Information and communications technologies consists of communication processes, computers, digital communications, information technology management, semiconductors, and telecommunications.

[2] Testing, measuring, and control consists of analysis of biological materials, control, measurement, and optics.

[3] Chemistry and health consists of pharmaceuticals, biotechnology, basic material chemistry, organic chemistry, macromolecular chemistry, chemical engineering, and medical technologies.

[4] Materials and nanotechnology consists of materials and metallurgy, microstructural and nanotechnology, and surface technology and coating.

[5] For a broader discussion of this trade and the role of intellectual property protection, see the White House (2015:Box 7-1).

Knowledge- and Technology-Intensive Economic Activity

S&E education and R&D investments lead to a highly skilled workforce and new S&E knowledge in the form of peer-reviewed articles, patents, and intangibles. Over time, these investments also contribute to economic activity in the form of products, services, and processes. S&E knowledge is increasingly a key input to production in the marketplace. Industries that intensely embody new knowledge and technological advances in their production, as reflected by their R&D expenditures and utilization of S&T in the delivery of their services, account for nearly one-third (31%) of global economic output. They span both manufacturing (e.g., aircraft and spacecraft; computer equipment; communications and semiconductors; chemicals and pharmaceuticals; testing, measuring, and control instruments; motor vehicles and parts; railroad and other transportation equipment; machinery) and services sectors (e.g., education, health, business, R&D, financial, and information services) (see Glossary; see Chapter 6 for a discussion of knowledge- and technology-intensive [KTI] industry categories).

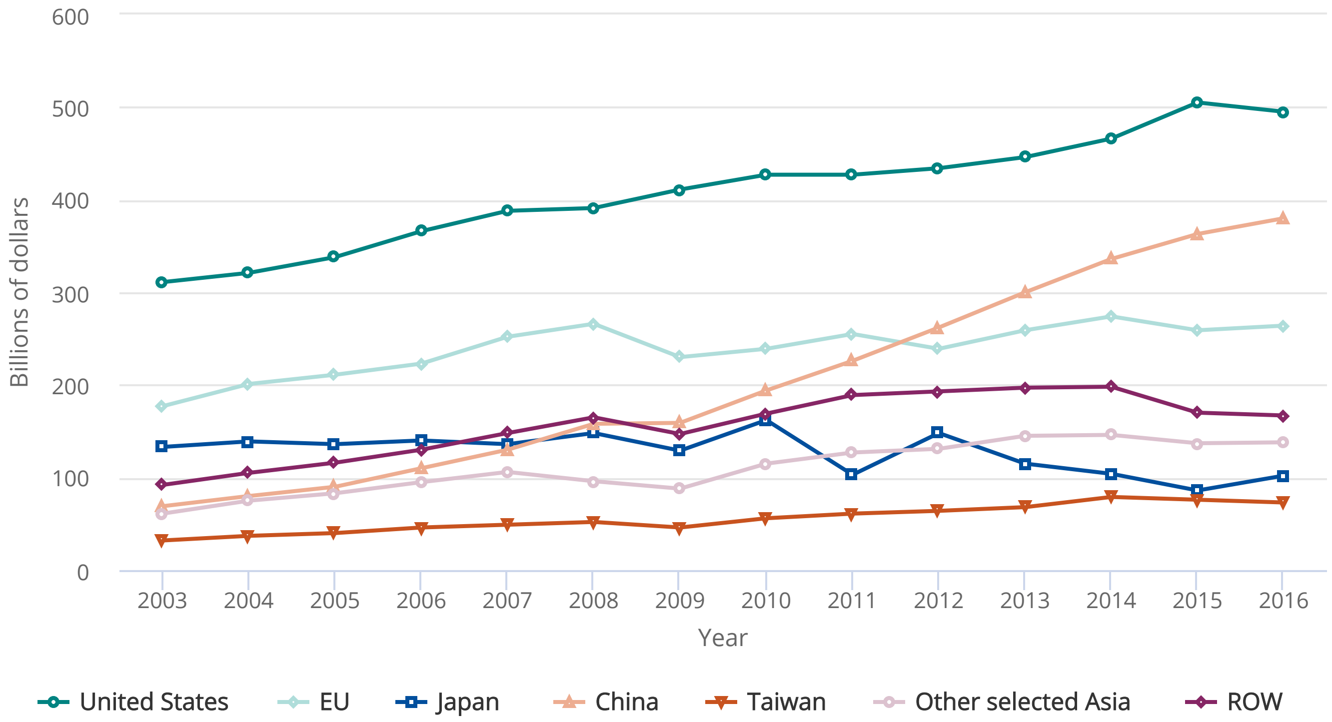
At 38%, the United States leads the major economies in the percentage of its GDP that comes from these KTI industries. Historically concentrated in the developed world, these industries typically make up a larger percentage of GDP in developed economies than in developing economies. However, developing economies, led by China, are emerging as prominent players as they ramp up their S&E capabilities. Additionally, recent global economic developments have had somewhat different impacts on the major global players, further transforming this segment of the S&E landscape. For example, following the global recession of the late-2000s, the United States has had strong growth in many KTI industries and trade of KTI goods and services, contrasting with tepid or negative growth in the EU and Japan. China has continued to grow quite robustly and has become the world's largest producer in many technology-intensive manufacturing industries. Although its relative position is not as strong in the knowledge-intensive (KI) services sector, where the United States and the EU are the dominant global producers, China is growing far more rapidly than developed economies overall.

The technology-intensive manufacturing industries are the most globalized among the KI industries. International trade and an interconnected global supply chain tie these KI industries across the globe and reflect the interdependence and the extent of globalization in the production process. For example, high-technology manufacturing industries, such as communications, semiconductors, and computers, have complex global value chains with manufacturing often located far away from the final markets. Medium-high-technology manufacturing industries, such as motor vehicles and parts and electrical equipment and appliances, also have global value chains, although manufacturing generally occurs near or in the final markets.

In high-technology manufacturing industries (which totaled $1.6 trillion in value-added terms in 2016), the United States and China were the largest global providers (31% and 24% of the global share, respectively); China's output rose sharply over time and now exceeds that of the EU (Figure O-16). Like the pattern of specialization seen in other S&E indicators, each region specializes in somewhat different types of activities. The United States has strength in aircraft and spacecraft and in measuring and control instruments. High-technology manufacturing of aircraft and spacecraft involves a supply chain of other high-technology inputs—navigational instruments, computing machinery, and communications equipment—many of which continue to be provided by U.S. suppliers.[1] The EU is also relatively strong in these two areas of aircraft and spacecraft and measuring and control instruments. China is the largest producer of a large subsector of high-technology manufacturing, information and communications technology (ICT), with a 34% global share.

FIGURE O-16

Output of HT manufacturing industries for selected regions, countries, or economies: 2003–16



EU = European Union; HT = high technology; ROW = rest of world.

Note(s)

Output of HT manufacturing is on a value-added basis. Value added is the amount contributed by a country, firm, or other entity to the value of a good or service and excludes purchases of domestic and imported materials and inputs. HT manufacturing industries are based on a former classification by the Organisation for Economic Co-operation and Development and include aircraft and spacecraft; communications; computers; pharmaceuticals; semiconductors; and testing, measuring, and control instruments. Data are not available for EU members Cyprus, Estonia, Latvia, Lithuania, Luxembourg, Malta, and Slovenia. China includes Hong Kong. Other selected Asia includes India, Indonesia, Malaysia, Philippines, Singapore, South Korea, and Vietnam.

Source(s)

IHS Global Insight, World Industry Service database (2017). See Appendix Table 6-7.

Science and Engineering Indicators 2018

Notwithstanding China's rapid advances, high-technology manufacturing in China continues to be heavily dependent on lower value-added activities, such as final assembly. In semiconductors, for example, although Chinese companies have gained global market share, China remains largely reliant on semiconductors supplied by foreign firms for most of its production of smartphones and other electronic products (PwC 2014). In the pharmaceutical sector (China is the third largest global producer of pharmaceuticals), output is largely made up of the production of generic drugs by Chinese-based firms and the establishment of production facilities controlled by U.S. and EU multinational corporations (MNCs) (Huang 2015). In contrast, the EU and the United States, the two largest global producers in pharmaceuticals, focus on biologics, vaccines, and stem cell therapies and closely integrate research, testing, and manufacturing of these pharmaceutical products (Donofrio and Whitefoot 2015:25). Many MNCs continue to conduct their higher value-added activities in developed countries because of the greater availability of skilled workers and stronger intellectual property protection.

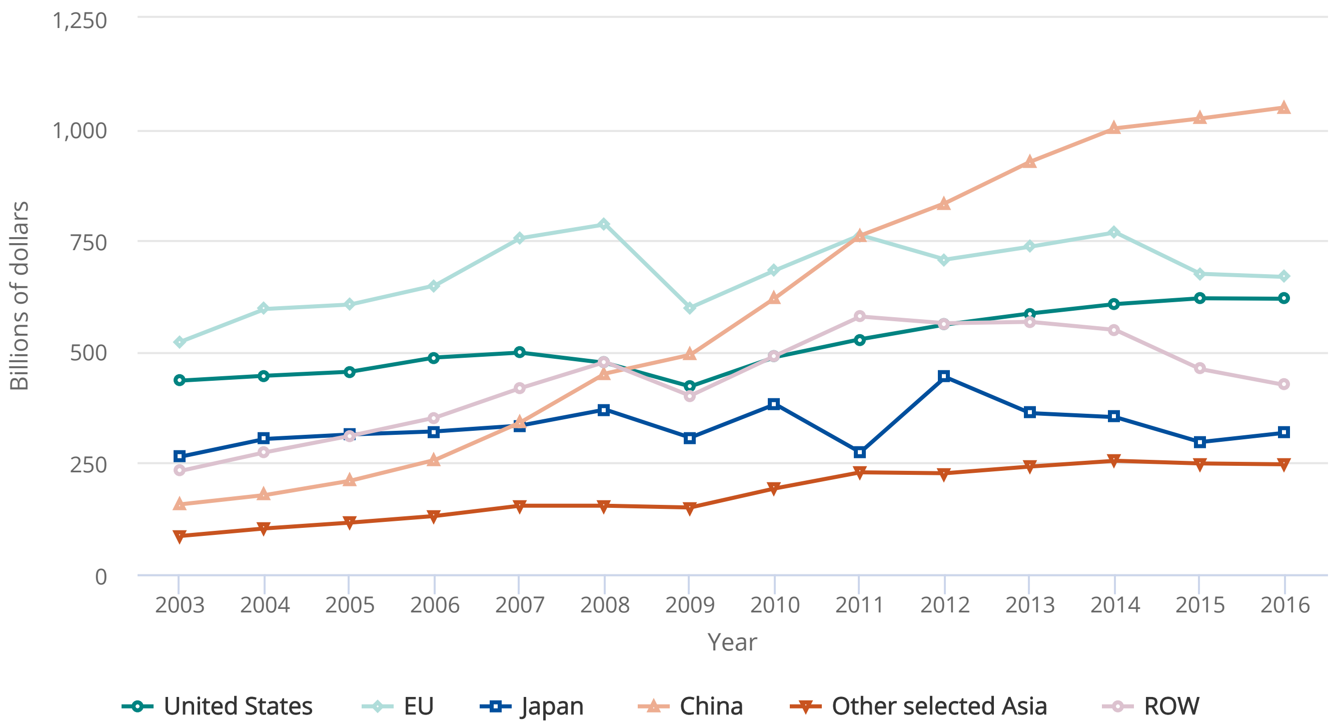
China's industry, however, is expected to move into emerging and complex technologies as companies continue to invest in R&D facilities and as research collaborations increase with academia (Donofrio and Whitefoot 2015:26). Recent developments indicate that China's rapid investments in building its S&E capabilities likely have already unfolded a potential path toward producing advanced products. For example, China has made impressive progress in its supercomputing ability over the last few years, an area in which it had little presence a decade ago, but where it now features prominently among the top 10 machines (see Chapter 6 sidebar China's Progress in Supercomputers).[2] The first large Chinese-made jetliner, the Comac C919, successfully completed its maiden test flight in 2017, a key step in China's plan to move up the value chain and become a global competitor in advanced technologies (Watt and Wong 2017).

A country's exports of KTI goods and services reflect its ability to compete in the world market. Globally, exports of high-technology products totaled $2.6 trillion in 2016 and are dominated by ICT products. China is the world's largest exporter of high-technology goods (24% of the global share) and has a substantial surplus (as measured by gross market value of traded products). However, because many of China's exports consist of inputs and components imported from other countries, China's exports and trade surplus are likely much less in value-added terms. The EU (17% global share), the United States (12%), and Taiwan (11%) are the next largest global exporters of high-technology goods. Vietnam has experienced the fastest rate of high-technology export growth of any single country and has become a low-cost location for assembly of cellular phones and smartphones and other ICT products, with some firms shifting production out of China, where labor costs are higher.

In medium-high-technology manufacturing industries (consisting of chemicals excluding pharmaceuticals, as well as machinery and equipment, motor vehicles and parts, electrical machinery and appliances, and railroad and other transportation equipment), global output totaled $3.3 trillion in value-added terms in 2016. Although these industries have global and often complex value chains, production activities are generally located closer to the final market compared to consumer electronics and other ICT industries with lightweight products (Donofrio and Whitefoot 2015:25). Transportation costs are high in many of these industries due to large and heavy products and components. Furthermore, co-location of R&D and design near the customers is advantageous for understanding customer needs and local market demand (Donofrio and Whitefoot 2015:25). China is the largest global producer (32% of the global share) (Figure O-17) in medium-high-technology manufacturing industries. The EU and the United States are roughly tied for second (with a 19%–20% global share each), and Japan is the third largest producer (10% of the global share).

FIGURE O-17

Output of MHT manufacturing industries for selected regions, countries, or economies: 2003–16



EU = European Union; MHT = medium-high technology; ROW = rest of world.

Note(s)

Output of MHT manufacturing is on a value-added basis. Value added is the amount contributed by a country, firm, or other entity to the value of a good or service and excludes purchases of domestic and imported materials and inputs. MHT manufacturing industries are based on a former classification by the Organisation for Economic Co-operation and Development and include automotive; chemicals (excluding pharmaceuticals); electrical machinery; motor vehicles; railroad, shipbuilding, and other transportation equipment; and machinery, equipment, and appliances. Data are not available for EU members Cyprus, Estonia, Latvia, Lithuania, Luxembourg, Malta, and Slovenia. China includes Hong Kong. Other selected Asia includes India, Indonesia, Malaysia, Philippines, Singapore, South Korea, Taiwan, and Vietnam.

Source(s)

IHS Global Insight, World Industry Service database (2017). See Appendix Table 6-7.

Science and Engineering Indicators 2018

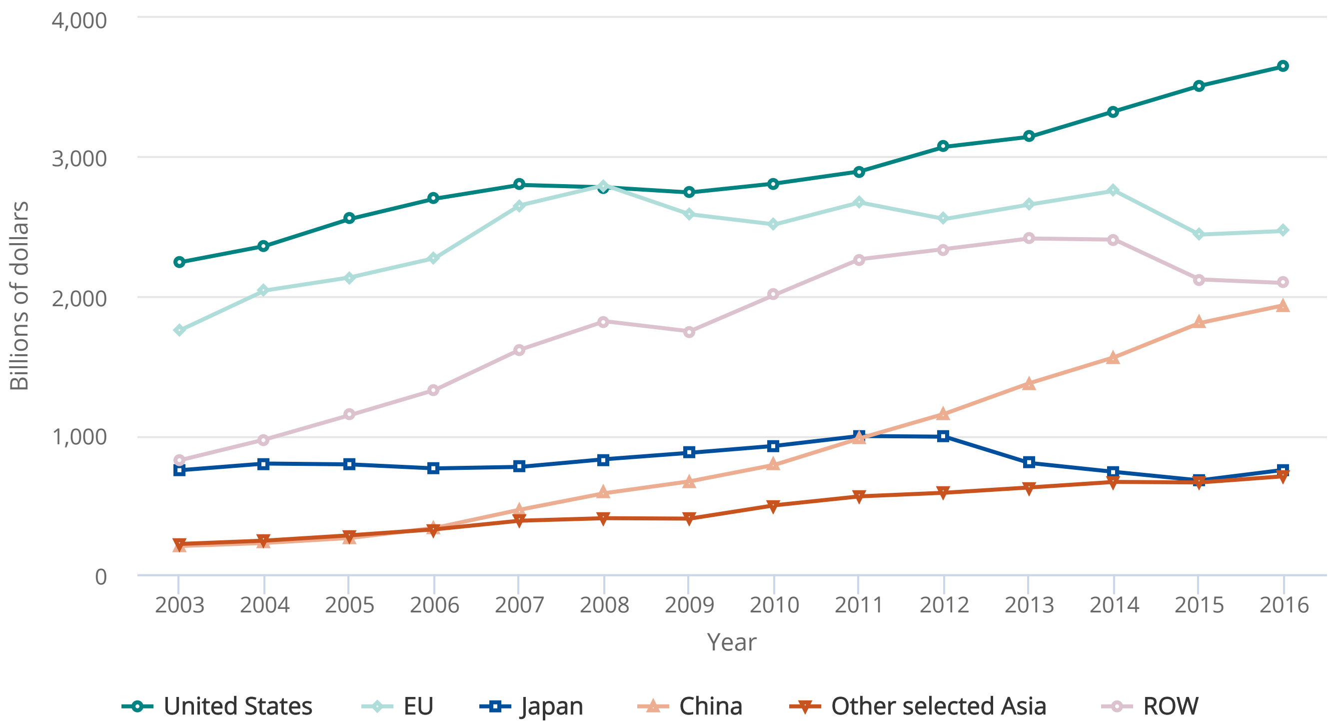
Globally, exports of medium-high-technology products totaled $3.4 trillion in 2016, with the EU being the largest exporter, followed by China, Japan, and the United States. The EU is the largest exporter in motor vehicles and parts, chemicals excluding pharmaceuticals, and machinery and equipment; China is the world's largest exporter in electrical machinery and appliances.

In addition to technology-intensive manufacturing, KTI industries also include the public KI services of education and health and a range of commercial services that totaled $11.6 trillion in value-added terms in 2016.[3] Commercial KI services include finance (banking, insurance, securities, stock market, etc.); business (engineering, consulting, and R&D services); and information services (computer programming and IT services).

Unlike technology-intensive manufacturing industries, more than half of the global output of commercial KI services comes from the United States (31%) and the EU (21%). China (17%) and Japan (6%) are the next largest global producers (📊 Figure O-18). Although China's relative position is not as strong in services as in manufacturing, China is making increasingly rapid progress. In the rest of the developing world, India and Indonesia accounted for growing shares of global commercial KI services output. India's growth was led by firms that provide business and computer services, such as IT and accounting, to developed countries. Indonesia had strong gains in financial services and business services.

FIGURE O-18

Output of commercial KI services industries for selected regions, countries, or economies: 2003–16



EU = European Union; KI = knowledge intensive; ROW = rest of world.

Note(s)

Output of commercial KI services is on a value-added basis. Value added is the amount contributed by a country, firm, or other entity to the value of a good or service and excludes purchases of domestic and imported materials and inputs. Commercial KI services are based on a former classification by the Organisation for Economic Co-operation and Development and include business, financial, and information services. Data are not available for EU members Cyprus, Estonia, Latvia, Lithuania, Luxembourg, Malta, and Slovenia. China includes Hong Kong. Other selected Asia includes India, Indonesia, Malaysia, Philippines, Singapore, South Korea, Taiwan, and Vietnam.

Source(s)

IHS Global Insight, World Industry Service database (2017). See Appendix Table 6-4.

Science and Engineering Indicators 2018

Globalization in the commercial KI services industries, although increasing, remains lower than in the high-technology or medium-high-technology manufacturing industries. Globally, exports of commercial KI services totaled $1.6 trillion in 2016. The trade of commercial KI services around the world is facilitated in part by the outsourcing activities of multinational corporations, taking advantage of economies with well-educated and multilingual populations. In 2016, the EU (33%) and the United States (18%) together accounted for about half of the global exports in commercial KI services, followed by India (7%) and China (6%). India, however, represents a considerable share (16%) of global exports in telecommunications, computer, and information services, reflecting the success of Indian firms in providing IT and other business services to developed countries.

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[1] Boeing sources about 70% of the parts from U.S.-based companies and 30% from companies outside the United States to produce its advanced 787 airliner and other similar models (CNN Money 2013).

[2] China had 18 of its supercomputers listed in the world's top 500 supercomputers in November 2016 (https://www.top500.org/statistics/sublist/).

[3] Public KI services—health and education—are much less market driven than other KTI industries. Additionally, international comparison of these sectors is complicated by variations in the size and distribution of each country's population, market structure, and degree of government involvement and regulation. As a result, differences in market-generated, value-added data may not accurately reflect differences in the relative value of these services. The Overview presents other indicators for education such as data on degrees awarded in Chapter 2.

Summary and Conclusion

Over the past quarter century, countries have increasingly come to view scientific and technical capabilities as engines of economic growth. Many countries have intensified efforts to build their S&T capabilities in a wide variety of areas and have become part of, and benefit from, the emerging global S&E landscape. Consequently, this landscape has undergone dramatic shifts: traditionally centered around the United States, Western Europe, and Japan, the S&E landscape is now increasingly multipolar. Generally, S&T growth has been faster in the developing than in the developed world, and the historically dominant developed nations have seen their relative share of global S&T activity shrink, even as their absolute activity levels kept rising. China's rapid, unprecedented, and sustained growth has been accompanied by developments in India, South Korea, and other Asian economies as countries around the world, building on their relative strengths, added to global S&T capabilities. These developments have taken place in the context of an increasingly interconnected world. Capacity building and enhancements in R&D, human capital, global supply chains, and other global infrastructure, along with dramatic changes in communications technologies, have facilitated the interconnected nature and greater international collaboration and competition in S&E activities.

Academic institutions in the developed world continue to be centers of excellence, conducting high-impact S&E research and providing graduate education in S&E to students from across the world. The United States continues to lead in the production of advanced degrees in S&E and high-impact S&E research as evidenced by shares of highly cited publications.

Academic institutions in the developing world have increased their production of graduates with S&E degrees, with China leading the growth in the number of these graduates. R&D expenditures in Asia have also grown rapidly, particularly in China and South Korea. In the United States and the EU, growth has continued but at a slower rate. As a result, China's R&D expenditures are now second only to those of the United States in annual magnitude. China's rapid growth in R&D expenditures and in S&E degrees (both at the bachelor's- and doctoral-degree levels) coincided with growth in S&E publications.

R&D concentration and intellectual property–related activities are increasingly multipolar; several relatively small economies appear to be specializing in S&E, as evidenced by high rates of R&D intensity in countries such as Israel (not shown), South Korea, Taiwan, and Singapore. Commercial S&E activity has a large concentration in parts of South and East Asia. Although Japan has been declining in some measures of S&E activates related to knowledge creation (such as its share of S&E publications), the country still rates highly in terms of total publications and patents granted. South Korea and Taiwan have experienced rapid growth in patenting and in intellectual property exports.

KTI production and trade account for increasing shares of global output and are closely related to country and regional investment in S&E education and in R&D activity. Production and assembly of high-technology goods have emerged in the developing world, particularly in China, where ICT and pharmaceutical manufacturing have become large shares of global production. Exports of high-technology products are centered in Asia, where China accounts for one-quarter of all such exports, but smaller nations such as Vietnam are rapidly expanding. This production activity, however, often represents the final phase of the global supply chain, where components designed or produced in other countries are transformed into final products, although China is gradually moving up the production value chain as it ramps up its S&E capabilities.

The developed world, particularly the economies of the United States, the EU, and Japan, maintains the bulk of KI commercial services production and exports, the assignment of patents, and receipts for the use of intellectual property. Intellectual property activities, in particular, are concentrated in developed economies, both large and small. These developments reflect S&E components of the global value chain, where different regions contribute to global activity based on relative strengths.

Overview of the State of the U.S. S&E Enterprise in a Global Context

The very nature of developments in S&T—unexpected insights, technological breakthroughs—along with general uncertainties in the broader national and global environment, preclude a simple projection of past trends into the future. In that sense, this Overview presents a snapshot of the world in a particular point in time. However, barring a major dislocation, careful analysis and interpretation of the related indicators presented here allow a realistic understanding of the likely overall direction of the global S&T landscape: dynamic, fast changing, integrated, interdependent, competitive, and tied together by a global infrastructure.

SIDEBAR

What Makes a Good Indicator?

Science and Engineering Indicators (*Indicators*) provides information on the state of the S&E enterprise in the United States and globally through high-quality quantitative data from domestic and international sources. The data are "indicators," that is, quantitative summary information on the scope, quality, and vitality of the science and engineering (S&E) enterprise or its change over time. The Methodology Appendix of the report provides detailed information on the methodological, statistical, and data-quality criteria used for the report. This sidebar provides a brief and high-level summary of the data sources used in this report and data-quality issues that influence the interpretation and accuracy of the information presented in *Indicators*.

First and foremost, a good indicator for use in the report explains something meaningful about the state of U.S. S&E in its global setting. The report provides multiple indicators to inform different aspects of a topic. These indicators are used by a wide variety of people and organizations with differing views about which indicators are the most significant for their specific purposes. Additionally, because each indicator provides a partial measure of overall activity, multiple indicators facilitate a more accurate and comprehensive understanding of the issue at hand.

A good indicator for the report is policy relevant, in that it contributes to an understanding of the current environment and to informing the development of future policies. *Indicators* data are used by policymakers at the federal-, state-, and local-government levels. A good indicator is also policy neutral, in that it provides an objective, balanced, and accurate description of the issue at hand. *Indicators* generally emphasizes neutral and factual description using simple statistical tools and then invites the exploration of more sophisticated causal models and relationships by the research community.

In addition, a good indicator provides an unbiased representation of its intended concept, with small enough measurement error to allow data users to make meaningful distinctions between the categories and time periods (Hall and Jaffe, 2012). When possible, the indicator is a direct measure of the intended concept, for example, the representation of different demographic groups in S&E jobs. In other cases, the intended concept is hard to measure directly and so related or proxy indicators are the best available. An example of this kind of indicator is S&E degree production (Chapter 2). The concept most data users are interested in is the capacity of the workforce to be productive in S&E fields, but the measure presented is S&E degrees earned.

Many of the indicators in the report are collected in surveys that are conducted by federal statistical agencies in the United States and other countries. Well-constructed surveys align the questions asked of respondents to the concepts that the indicator is intended to measure and provide the detailed category breakdowns that are most relevant to data users. How well the survey-based indicator represents the intended population depends on how well the survey has been able to obtain responses from the targeted population. The indicator's precision, or inherent variability, depends on number of respondents; more is better.

Some indicators used in the report come not from surveys but from data collected by companies, governments, and organizations as part of their ongoing internal activities; these data are administrative data. Patent and bibliometric data (Chapter 5, Chapter 6, and Chapter 8) are two examples. Because the data collection was not originally intended as an indicator, these data may not fully correspond to the intended use for *Indicators* and may not fully represent the desired population. Good features of these kinds of data are that the respondent burden is low because the data already exist, data sets are often very large, and the data source often has structured the data carefully, though generally for uses other than as an indicator. Additionally, these data are often available with a shorter delay than is possible with survey data production cycles. In these cases, transparency about the difference between the concept intended and the actual data provided allows a partial indicator to be a good one as well.

Indicators is prepared for the National Science Board by the National Center for Science and Engineering Statistics (NCSES), a federal statistical agency within the National Science Foundation. Many of the individual indicators presented are from NCSES's own surveys as well as from U.S. and other nations' statistical agencies. To ensure the quality of the indicators, wherever possible international data comparisons are presented using data that have been harmonized by international organizations, such as the Organisation for Economic Co-operation and Development and the United Nations, or has been prepared for NCSES across countries using consistent standards.

Glossary

Definitions

Commercial knowledge-intensive (KI) services: Knowledge-intensive services that are generally privately owned and compete in the marketplace without public support. These services are business, information, and financial services.

European Union (EU): The EU comprises 28 member nations: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, and the United Kingdom. Unless otherwise noted, data on the EU include all 28 nations.

High-technology manufacturing industries: Industries formerly classified by the Organisation for Economic Co-operation and Development that spend a high proportion of their revenue on R&D. These industries consist of aerospace; pharmaceuticals; computers and office machinery; semiconductors and communications equipment; and measuring, medical, navigation, optical, and testing instruments.

Information and communications technologies (ICT) industries: A subset of knowledge- and technology-intensive industries, consisting of two high-technology manufacturing industries, computers and office machinery and communications equipment and semiconductors, and two knowledge-intensive services industries, information services and computer services, which is a subset of business services.

Invention: The development of something new that has a practical bent—potentially useful, previously unknown, and nonobvious.

Innovation: The implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organization method in business practices, workplace organization, or external relations (OECD/Eurostat 2005).

Knowledge transfer: The process by which technology or knowledge developed in one place or for one purpose is applied in another place for the same or a different purpose. This transfer can take place freely or through exchange and either deliberately or unintentionally. In the federal setting, technology transfer is the process by which existing knowledge, facilities, or capabilities developed under federal R&D funding are used to fulfill public and private needs.

Knowledge- and technology-intensive (KTI) industries: Those industries that have a particularly strong link to science and technology. These industries are five service industries (financial, business, communications, education, and health care); five high-technology manufacturing industries (aerospace, pharmaceuticals, computers and office machinery, semiconductors and communications equipment, and measuring, medical, navigation, optical, and testing instruments); and five medium-high-technology industries (motor vehicles and parts, chemicals excluding pharmaceuticals, electrical machinery and appliances, machinery and equipment, and railroad and other transportation equipment).

Knowledge-intensive (KI) services industries: Those industries that incorporate science, engineering, and technology into their services or the delivery of their services, consisting of business, information, education, financial, and health care.

Medium-high-technology manufacturing industries: Industries formerly classified by the Organisation for Economic Co-operation and Development that spend a relatively high proportion of their revenue on R&D. These industries consist of motor vehicles and parts, chemicals excluding pharmaceuticals as well as electrical machinery and appliances, machinery and equipment, and railroad and other transportation equipment.

Research and development (R&D): Research and experimental development comprise creative and systematic work undertaken to increase the stock of knowledge—including knowledge of humankind, culture, and society—and its use to devise new applications of available knowledge.

Basic research: Experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, without any particular application or use in view.

Applied research: Original investigation undertaken to acquire new knowledge; directed primarily, however, toward a specific, practical aim or objective.

Experimental development: Systematic work, drawing on knowledge gained from research and practical experience and producing additional knowledge, which is directed to producing new products or processes or to improving existing products or processes (OECD 2015).

R&D intensity: A measure of R&D expenditures relative to size, production, financial, or other characteristics for a given R&D-performing unit (e.g., country, sector, company). Examples include R&D-to-GDP ratio and R&D-to-value-added output ratio.

Value added: A measure of industry production that is the amount contributed by a country, firm, or other entity to the value of the good or service. It excludes double-counting of the country, industry, firm, or other entity purchases of domestic and imported supplies and inputs from other countries, industries, firms, and other entities.

Key to Acronyms and Abbreviations

ARRA: American Recovery and Reinvestment Act

EC: European Commission

EU: European Union

FFRDC: federally funded R&D center

GDP: gross domestic product

HT: high technology

ICT: information and communications technologies

IPEDS: Integrated Postsecondary Education Data System

IT: information technology

KI: knowledge intensive

KTI: knowledge- and technology-intensive

MHT: medium-high technology

MNC: multinational corporation

NCSES: National Center for Science and Engineering Statistics

OECD: Organisation for Economic Co-operation and Development

PPP: purchasing power parity

R&D: research and development

ROW: rest of world

S&E: science and engineering

S&T: science and technology

UNESCO: United Nations Educational, Scientific and Cultural Organization

USPTO: U.S. Patent and Trademark Office

WebCASPAR: Integrated Science and Engineering Resources Data System

WIPO: World Intellectual Property Organization

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CHAPTER 1

Elementary and Secondary Mathematics and Science Education

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Highlights

Student Learning in Mathematics and Science

The National Assessment of Educational Progress (NAEP) mathematics assessment results show that average mathematics scores for fourth, eighth, and twelfth graders declined slightly for the first time in 2015 and remained flat or showed only small gains between 2005 and 2015.

- The average NAEP mathematics score in 2015 declined by 2 points for fourth graders, 3 points for eighth graders, and 1 point for twelfth graders compared with 2013. These are the first declines since 1990 for fourth and eighth graders and since 2005 for twelfth graders.
- Although the long-term trend in average scores for fourth and eighth graders has been upward, the improvement slowed down this past decade. From 2005 to 2015, average NAEP mathematics scores increased by 2 points for fourth graders and 3 points for eighth graders; in comparison, from 1996 to 2005, the average scores increased by 14 points for fourth graders and 9 points for eighth graders.

NAEP science assessment results show that average scores increased slightly in 2015 for fourth and eighth graders but stayed similar for twelfth graders.

- The average NAEP science scores increased 4 points between 2009 and 2015 in grades 4 and 8 but did not change in grade 12.

Less than half of fourth, eighth, and twelfth grade students achieved a level of proficient (defined as “solid academic performance”) or higher on NAEP mathematics and science assessments in 2015.

- Forty percent of fourth graders, 33% of eighth graders, and 25% of twelfth graders achieved a level of proficient or higher in mathematics in 2015.
- Approximately 38% of fourth graders, 34% of eighth graders, and 22% of twelfth graders achieved a level of proficient or higher on the NAEP science assessment in 2015.

Performance disparities in mathematics and science were evident among different demographic groups at all grade levels.

- Average scores on 2015 NAEP mathematics and science assessments for fourth, eighth, and twelfth grade students who were eligible for free or reduced-price lunch (an indicator of socioeconomic status) were 23 to 29 points lower than the scores of their peers who were not eligible for the program.
- Performance gaps between white students and black and Hispanic students showed similar patterns across all NAEP assessments and grade levels, with average scores of white students at least 18 points higher than those of Hispanic students and at least 24 points higher than those of black students.
- Score differences between students eligible for free or reduced-price lunch and those who were not persisted within racial or ethnic groups. For example, the gaps between eligible and non-eligible students in grade 4 mathematics were 18 points among white students, 17 points among Hispanic students, and 16 points among black students. Similar gaps held among eighth and twelfth grade students and across all grade levels in science.

- Gaps between male and female students on NAEP mathematics and science assessments were small, with average score differences of two to five points in favor of male students. There was no difference in average scores by sex for grade 8 mathematics or grade 4 science.

Performance disparities in mathematics and science begin as early as kindergarten and persist through subsequent school years.

- A study based on the mathematics and science assessment scores among the kindergarten class of 2010–11 shows that gaps in average scores by race or ethnicity and family income level evident in kindergarten do not narrow by the end of third grade.
- The gap in average mathematics scores between students in families with income below the federal poverty level and those in families with income at or above 200% of the federal poverty level was 9 points at the beginning of kindergarten and 10 points by the spring of third grade; the science score gap was 5 points at the beginning of first grade and 8 points by the spring of third grade.
- The gap in average mathematics scores between white and black students was 6 points at the beginning of kindergarten and 13 points in the spring of third grade; the science score gap was 5 points at the beginning of first grade and 9 points by the spring of third grade.

In the international arena, the Trends in International Mathematics and Science Study (TIMSS) and the Program for International Student Assessment (PISA) 2015 data show that the U.S. average mathematics assessment scores were well below the average scores of the top-performing education systems.

- On the TIMSS mathematics assessment, average scores for the top five performers—Singapore, Hong Kong, South Korea, Taiwan, and Japan—were at least 54 points higher than the United States at grade 4 (593–618 versus 539) and at least 68 points higher than the United States at grade 8 (586–621 versus 518).
- The United States' average score of 470 on the PISA mathematics literacy assessment for 15-year-olds was at least 62 points below the average scores (532–564) of the top five performers—Singapore, Hong Kong, Macau, Taiwan, and Japan.

TIMSS data show that U.S. fourth and eighth graders have raised their scores over the 20 years since administration of the first TIMSS mathematics assessment in 1995.

- Between 1995 and 2015, the average mathematics score increased by 21 points for fourth graders and by 26 points for eighth graders.

The 2015 data from PISA indicate that the United States performs better internationally in science literacy than it does in mathematics literacy.

- The United States' average science literacy score of 493 was not significantly different from the Organisation for Economic Co-operation and Development (OECD) average and put the United States behind 18 other education systems. In contrast, the mathematics literacy score was below the OECD average and put the United States behind 36 other education systems.

High School Coursetaking in Mathematics and Science

Among ninth graders who entered high school in 2009 and completed high school in 2013, the vast majority (89%) completed algebra 2 or higher in mathematics, and nearly all (98%) completed biology in science.

- Approximately one-quarter of students stopped with algebra 2 as their highest mathematics course, another quarter stopped with trigonometry or other advanced mathematics, 22% advanced to pre-calculus, and 19% finished with calculus or higher.
- In addition to taking biology, 76% of ninth graders who began high school in 2009 took chemistry and 42% took physics by the time they completed high school in 2013.

The number of high school students who take Advanced Placement (AP) exams in mathematics and science continues to rise.

- Calculus AB is the most common mathematics AP exam. The number of students who took an AP exam in calculus AB increased from 197,000 in 2006 to more than 308,000 in 2016.
- Biology is the most common science AP exam. The number of students who took an AP exam in biology increased from nearly 132,000 in 2006 to 238,000 in 2016.
- Computer science A is the fastest-growing AP exam, with the number of students taking the exam growing nearly four-fold from just under 15,000 in 2006 to nearly 58,000 in 2016.
- Passing rates for the mathematics and science AP exams in 2016 ranged from lows of 40% for physics 1 and 46% for environmental science to highs of 77% for physics C: mechanics and 81% for calculus BC.

Teachers of Mathematics and Science

The majority of K−12 mathematics and science teachers held a teaching certificate and had taught their subjects for 3 years or more.

- In 2011, the vast majority of public middle and high school mathematics (91%) and science (92%) teachers were fully certified (i.e., held regular or advanced state certification).
- In 2011, 85% of public middle and high school mathematics teachers and 90% of science teachers had more than 3 years of teaching experience.

Fully certified, well-prepared, and experienced teachers were not evenly distributed across schools or classes.

- Fully certified mathematics and science teachers were less prevalent in high-minority and high-poverty schools when compared with schools with students from higher-income families. For example, in 2011, 88% of mathematics teachers in high-poverty schools were fully certified, compared with 95% of those in low-poverty schools.
- At the middle school level, in 2011, 75% of mathematics teachers in low-poverty schools had in-field degrees, compared with 63% of teachers at high-poverty schools.
- At the high school level, 95% of mathematics teachers at low-poverty schools had in-field degrees, compared with 87% at high-poverty schools.
- The percentage of mathematics teachers with fewer than 3 years of experience was higher at high-poverty schools (18%) than at low-poverty schools (10%). The pattern was similar for science teachers.

In 2011, the average base salary of middle and high school teachers was approximately $53,000 for mathematics teachers and $54,000 for science teachers.

- Compensation for U.S. mathematics and science teachers was nearly equivalent to that of teachers of other subjects in 2011.
- In the international arena, the United States ranks low among developed countries with respect to teachers' salaries relative to the salaries of other college-educated workers. For primary school teachers, the U.S. ranking is 20th of 23 countries. For lower and upper secondary school teachers, the United States is 21st of 23 countries.

Instructional Technology and Digital Learning

The use of instructional technology in K−12 classrooms has grown, and the number of schools with adequate bandwidth for accessing the Internet has increased.

- In 2009, 97% of K–12 public school teachers reported that they had one or more computers in their classroom, and 69% said that they or their students often or sometimes used computers during class time.
- In 2016, more than two-thirds of school district technology administrators indicated that all the schools in their district fully met the Federal Communication Commission's Internet bandwidth recommendations for public schools, up from 19% in 2012.
- National data available to address the quality and effectiveness of technology-based educational programs delivered in classrooms remain limited; available research has generally shown only modest positive effects of technology on learning.

The number of students participating in online learning has also risen.

- In the 2014–15 school year, 24 states operated virtual schools that offered supplemental online courses for students. These schools served more than 462,000 students, who took a total of 815,000 online semester-long courses. Although still a small fraction of the approximately 50 million students enrolled in K–12 public schools, this was a substantial increase since 2012–13, when 721,149 semester course enrollments were recorded.
- High school students took most of these courses (85%). Math courses made up nearly 23% of the courses taken, and science courses made up 14%.

Transition to Higher Education

U.S. on-time high school graduation rates have improved steadily.

- In 2011, 79% of public high school students graduated on time with a regular diploma; by 2015, the figure had climbed to 83%.
- Although on-time graduation rates for economically disadvantaged students have improved by 6 percentage points since 2011, these students continue to graduate at lower rates than the general population (76% versus 83% in 2015).

Significant racial and ethnic differences persisted, with white and Asian or Pacific Islander students having higher graduation rates than other racial or ethnic subgroups.

- In 2015, the on-time high school graduation rates for Asian or Pacific Islander and white students were 90% and 88%, respectively; and both rates surpassed those of black, Hispanic, and American Indian or Alaska Native students (72%–78%) by at least 10 percentage points.

Immediate college enrollment rates have increased for all students from 1975 to 2015, although differences remain for demographic groups.

- Between 1975 and 2015, the percentage of high school graduates making an immediate transition to college increased from 51% to 69%.
- In 2015, the immediate college enrollment rate of students from low-income families was 14 percentage points lower than the rate of those from high-income families (69% versus 83%).
- Enrollment rates also varied widely with parental education, ranging in 2015 from 56% for students whose parents had less than a high school education to 82% for students whose parents had a bachelor's degree or higher.

Introduction

Chapter Overview

Elementary and secondary education in mathematics and science is the foundation of human capital that advances science and engineering research, technology development, innovation, and economic growth. Every U.S.-educated scientist and engineer begins his or her science, technology, engineering, and mathematics (STEM) education in the K–12 grades. There, talents may be built or discovered, interest in STEM cultivated, and knowledge acquired that allows students to succeed in pursuing STEM degrees in postsecondary education. For those who do not pursue STEM, the mathematics and science knowledge needed to function as consumers and citizens emerges largely from K–12 education. Within this context, federal and state policymakers, educators, and legislators are working to broaden and strengthen STEM education at the K–12 level. Efforts to improve mathematics and science learning include promoting early participation in STEM in the elementary grades, increasing advanced coursetaking in high school, recruiting and training more mathematics and science teachers, and expanding secondary education programs that prepare students to enter STEM fields in college.

The Every Student Succeeds Act (ESSA), the first reauthorization of the Elementary and Secondary Education Act in nearly a decade, was signed into law in late 2015. The act identifies STEM as a crucial component of a well-rounded education for all students. It also allows states to act on a variety of STEM priorities, including mathematics and science standards and assessment, recruitment and training of STEM teachers, formation of STEM specialty schools, and increased access to STEM for underserved and at-risk student populations. ESSA also provides new focus on engineering and technology by explicitly including computer science in its definition of STEM and by allocating federal funds to help states integrate engineering and technology into their science standards and assessments.

Educators have joined a state-led effort to develop common national K–12 mathematics and science standards, as well as assessments and indicators for monitoring progress in K−12 mathematics and science teaching and learning. Many states have adopted and implemented the Common Core State Standards in mathematics, and 18 states and the District of

Columbia have adopted the Next Generation Science Standards. Progress is also being made on a national system for monitoring progress in STEM education (see sidebar 💬 Developing a K–12 STEM Education Indicator System).

SIDEBAR

Developing a K–12 STEM Education Indicator System

In 2011, the National Research Council (NRC) released *Successful K-12 STEM Education: Identifying Effective Approaches in Science, Technology, Engineering, and Mathematics*, which describes the components of successful science, technology, engineering, and mathematics (STEM) education (National Research Council [NRC] 2011). In response, Congress requested that the National Science Foundation (NSF) identify methods for tracking and evaluating the implementation of the components recommended by the NRC. An NRC-convened committee authored a second report that outlined 14 indicators of successful STEM education that could be monitored and tracked, including markers of students' access to quality learning, educators' capacity, and STEM policy and funding initiatives (NRC 2013). The report also addressed the need for research and data that could be used to measure progress on each indicator, noting that many of the indicators required new kinds of data collection, additional research, and conceptual development.

The STEM Indicators project has identified data sources that can be used for the indicators and other areas in which new data sources are needed (http://stemindicators.org/). New data sources include new questions on the National Teacher and Principal Survey of 2017–18, which will collect, for the first time, data on STEM school magnet programs, the amount of instructional time devoted to science, and teacher professional development in STEM topics. NSF has funded 15 research projects investigating valid and reliable measurement of the indicators and has initiated another grant cycle for additional research and development (http://stemindicators.org/stem-education-researchers/dclprojects/).

Chapter Organization

To provide a portrait of K−12 STEM education in the United States, including comparisons of U.S. student performance with that of other nations, this chapter compiles indicators of pre-college mathematics and science teaching and learning based mainly on data from the National Center for Education Statistics (NCES) of the Department of Education, supplemented by other public sources. Table 1-1 contains an overview of the topics covered in this chapter and the indicators used to address them. Whenever a comparative statistic is cited in this chapter, it is statistically significant at the 0.05 probability level.

This chapter focuses on overall patterns in STEM education and reports variation in STEM access and performance by students' socioeconomic status (SES), race or ethnicity, and sex. The chapter also examines differences by SES and sex within racial or ethnic groups. Research suggests that STEM education can provide historically underrepresented populations with pathways for obtaining good jobs and a higher standard of living, if they can access these opportunities (Doerschuk et al. 2016; Leadership Conference Education Fund 2015; Wang and Degol 2016). Data in this chapter reveal consistent achievement and opportunity gaps in STEM education across the K–12 spectrum. With few exceptions, the data show major, substantial effects of SES on achievement levels, early and persisting differences among racial or ethnic groups, often substantial achievement differences by SES within racial or ethnic groups, and some differences in male and female achievement. These results are consistent across all types of data discussed, including tests of different student panels, tests that follow specific age cohorts, international tests, student coursetaking in high school, on-time high school graduation rates, scores on college readiness assessments, and immediate college enrollment rates.

This chapter is organized into five sections. The first section presents indicators of U.S. students' performance in STEM subjects in elementary and secondary school. It begins with a review of national trends in mathematics and science assessment scores in grades 4, 8, and 12, using data from the National Assessment of Educational Progress (NAEP). The NAEP section also includes data from a new assessment of eighth graders' technology and engineering literacy. Next, the section presents data from a longitudinal study that tracks individual students' growth in mathematics and science knowledge over time: the Early Childhood Longitudinal Study, Kindergarten Class of 2010–11 (ECLS-K:2011). The section ends by placing U.S. student performance in an international context, using data from two international studies: the Trends in International Mathematics and Science Study (TIMSS), which examines the mathematics and science performance of students in grades 4, 8, and 12; and the Program for International Student Assessment (PISA), which examines the mathematics and science literacy of 15-year-olds.

The second section focuses on STEM coursetaking in high school. Using data from NCES's High School Longitudinal Study of 2009 (HSLS:09), data from the College Board's Advanced Placement (AP) program, and data collected by the Department of Education's Office for Civil Rights, it examines high school students' participation in mathematics and science courses, including engineering and computer science.

The third section turns to U.S. elementary, middle, and high school mathematics and science teachers, reviewing data presented in *Science and Engineering Indicators 2016* (National Science Board [NSB] 2016) and presenting new data comparing U.S. teachers' salaries with those of their peers in other countries.

The fourth section examines how technology is used in K−12 education. The section begins by presenting the latest national data on the availability or use of various technological devices in classrooms, Internet access in schools, and the prevalence of online learning among K–12 students. It then provides a review of research on the effectiveness of technology as an instructional tool to improve student learning outcomes.

The fifth section focuses on indicators related to U.S. students' transitions from high school to postsecondary education. It presents national data for on-time high school graduation rates, trends in immediate college enrollment after high school, academic readiness for college, and students' plans to major in a STEM subject in college. This section also examines the high school graduation rates of U.S. students relative to those of their peers in other countries. Together, these indicators present a broad picture of the transition of U.S. students from high school to postsecondary education, the topic of Chapter 2.

TABLE 1-1

Indicators of elementary and secondary school mathematics and science education

(Topic and indicator)

Topic	Indicator
Student learning in mathematics and science	• Trends in fourth, eighth, and twelfth graders’ mathematics performance through 2015 • Eighth graders' technology and engineering literacy in 2014 • Mathematics and science performance of first-time kindergarten students in the 2012−13 and 2013−14 school years • International comparisons of mathematics and science performance of students in grades 4, 8, and 12 in 2015 • International comparisons of 15-year-olds’ mathematics and science literacy in 2015
Student coursetaking in mathematics and science	• Highest mathematics and science course enrollment of high school completers in 2013 • Trends in participation and performance in the Advanced Placement program from 2006 to 2016
Teachers of mathematics and science	• Certification, experience, and salaries of U.S. mathematics and science teachers in 2012 • International comparisons of teacher salaries in 2014
Instructional technology and digital learning	• Review of emerging practices of instructional technology and online learning and their effects on student learning
Transitions to higher education	• Trends in on-time high school graduation rates from 2011 to 2015 • International comparisons of secondary school graduation rates in 2014 • Immediate college enrollment from 1975 to 2013 • High school students reporting plans for a postsecondary STEM major in 2013 • High school students meeting college readiness benchmarks in 2016

STEM = science, technology, engineering, and mathematics.

Science and Engineering Indicators 2018

Student Learning in Mathematics and Science

Increasing academic achievement for *all* students—with an emphasis on improving the performance of low-achieving students—is a critical goal of education reform in the United States. It is equally important to increase the number and diversity of students achieving at the highest academic levels. Many educators and policymakers focus on improving student learning in STEM subjects because workers’ proficiency in STEM fields is considered vital to the health of the economy (Atkinson and Mayo 2010; PCAST 2012). This section presents indicators of U.S. students’ performance in STEM subjects in elementary and secondary school. It begins with a review of national trends in scores on mathematics and science assessments, using data from NAEP. Next, it presents data from ECLS-K:2011, which focused on students’ growth from kindergarten to third grade. The section ends by placing U.S. student performance in an international context, comparing the mathematics and science literacy of U.S. 15-year-olds and the mathematics and science performance of U.S. fourth, eighth, and twelfth graders with those of their peers in other countries.

National Trends in K–12 Student Achievement

This subsection looks at trends in U.S. students' achievement in mathematics and science over time, presenting estimates from NAEP, the largest nationally representative and continuing assessment of what America's students know and can do in various subject areas. Contributing to this review are 2015 data from the main NAEP mathematics and science assessments of students in grades 4, 8, and 12. All NAEP assessments include students from public and private schools, so results are representative of the in-school population in the United States. Comparable NAEP data are available beginning in 1990 for mathematics for grades 4 and 8 and beginning in 2005 for grade 12.[1] Comparable science data are available since 2009 for all three grades.[2] NAEP 2015 includes the first science achievement data collected for fourth and twelfth graders in 6 years and for eighth graders in 4 years. The section also provides information about student performance in technology and engineering, based on results from a new NAEP assessment, technology and engineering literacy (TEL), which was first administered to eighth graders in 2014. TEL will be administered to students in grades 4 and 12 in future years.

Reporting Results for the Main NAEP

The main NAEP reports student performance in two ways: scale scores and student achievement levels. A scaled score is the total number of correct questions (raw score) on an exam that have been converted onto a consistent and standardized scale. This standardization allows scores reported from a test to have consistent meaning for all test takers, especially across different editions of the same test. Main NAEP scale scores range from 0 to 500 for grades 4 and 8 and from 0 to 300 for grade 12 on the mathematics assessment. On the science and TEL assessments, however, the scale scores range from 0 to 300 for all students. With broad input from the public, educators, and policymakers, the National Assessment Governing Board (NAGB), an independent board that sets policy for NAEP, has developed achievement levels that indicate the extent of students' achievement expected for a particular grade level. There has been some debate that these levels may be too rigorous; thus, results should be interpreted with caution (Loveless 2016).[3] The three grade-specific achievement levels for mathematics, science, and technology/engineering literacy are the following:

Basic: partial mastery of knowledge and skills

Proficient: solid academic performance

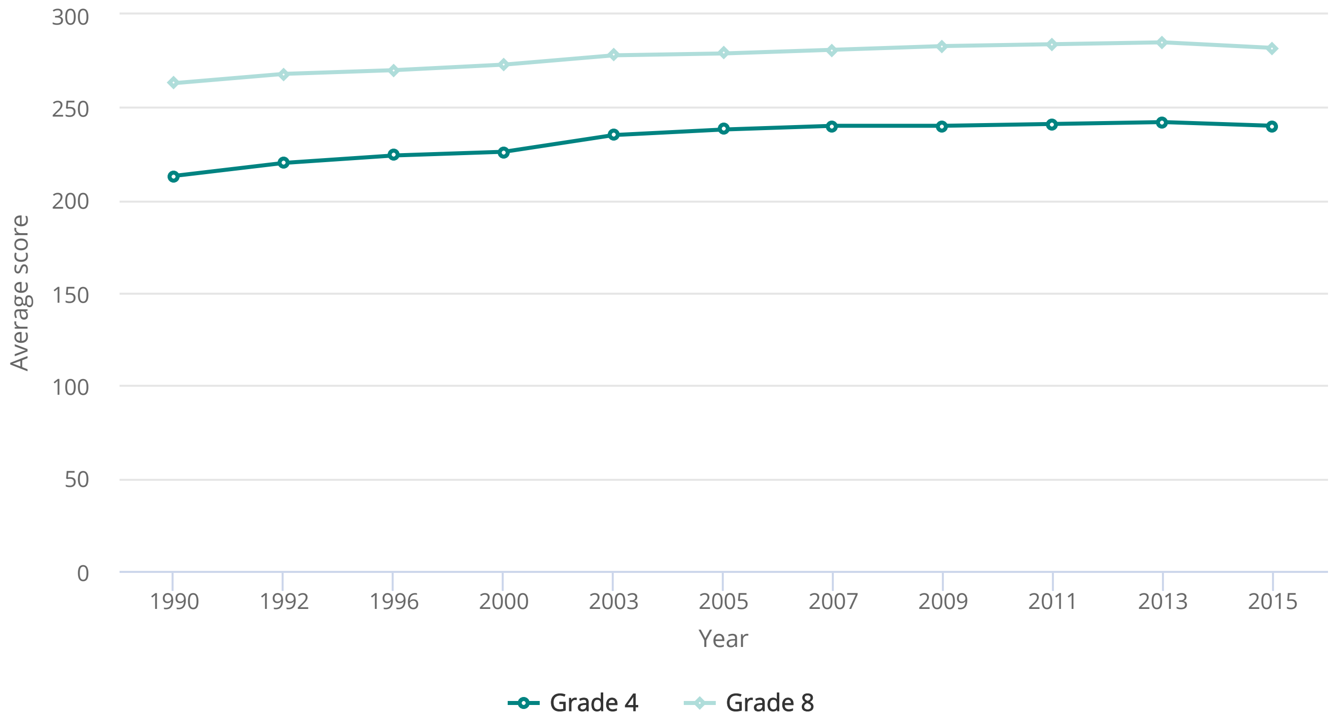
Advanced: superior academic performance

Mathematics Performance of Students in Grades 4, 8, and 12 in 2015

Average score. The average NAEP mathematics score in 2015 was 240 for fourth graders, 282 for eighth graders, and 152 for twelfth graders (Appendix Table 1-1). These scores represent a slight decline from 2013, when the scores were 242, 285, and 153, respectively. These are the first declines in NAEP mathematics assessments since 1990 for fourth and eighth graders and since 2005 for twelfth graders, although these are small changes and may be a natural fluctuation rather than the start of a downward trend. Although the scale is 0 to 500 for the fourth and eighth grade assessments and 0 to 300 for the twelfth grade, it is important to note that the effective score range (i.e., the range from the 10th to the 90th percentiles) for the preponderance of students is less than 100 points, which puts the magnitude of score differences in context. Eighty percent of fourth graders scored between 202 and 277, 80% of eighth graders scored between 235 and 329, and 80% of twelfth graders scored between 107 and 196. Although the long-term trend in average scores for fourth and eighth graders has been upward, the improvement slowed down this past decade. From 2005 to 2015, average NAEP mathematics scores increased by 2 points for fourth graders and 3 points for eighth graders; in comparison, from 1996 to 2005, the average scores increased by 14 points for fourth graders and 9 points for eighth graders (📊 Figure 1-1).

FIGURE 1-1

Average NAEP mathematics scores of students in grades 4 and 8: 1990–2015



NAEP = National Assessment of Educational Progress.

Note(s)

NAEP mathematics assessment scores range from 0 to 500 for grades 4 and 8.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2016) of NAEP 1990, 1992, 1996, 2000, 2003, 2005, 2007, 2009, 2011, 2013, and 2015 mathematics assessments, National Center for Education Statistics. See Appendix Table 1-1.

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Socioeconomic status. NAEP uses eligibility for the National School Lunch Program (NSLP) as an indicator for SES, with eligibility for the program considered an indicator of SES. It is widely understood that eligibility for the NSLP is an inadequate measure of student poverty or SES for a variety of reasons (Cowan et al. 2012; Snyder and Musu-Gillette 2015). For example, students above the federal poverty level may still qualify for the NSLP, and a comprehensive measure of a student's SES would include such factors as parental education and occupation in addition to measures of poverty. NAGB and others continue to report school lunch eligibility as a proxy for SES because it is the only measure that is available at the school level. Information on family income, parental education, parental occupation, and other factors needed to better capture SES are not readily available. NAGB is pursuing other ways to report SES for students taking NAEP exams. In the meantime, readers should interpret SES results reported here with the understanding that eligibility for school lunch is not a precise measure of the construct.

Average 2015 NAEP mathematics assessment scores varied by school lunch eligibility for all grade levels, with eligible students posting average scores from 23 to 28 points lower than non-eligible students (Appendix Table 1-1). In the past decade, the gap between eligible and non-eligible students did not decrease in size at any grade level.

Race or ethnicity. Scores also varied by race or ethnicity at all grade levels, with Asian or Pacific Islander students receiving the highest average scores at all three grade levels (Appendix Table 1-1). In 2015, for example, average mathematics scores for eighth graders were 306 for Asian or Pacific Islander students, 292 for white students, 270 for Hispanic students, and 260 for black students. It is important to note that these are average scores, however, and that students from all groups score at the higher and lower ends of the score distributions. Fourth and eighth grade Hispanic and black students reduced gaps relative to white students between 2005 and 2015. Although the average score for white students in grade 4 increased by 2 points after 2005, the average score rose by 4 points for Hispanic students and by 4 points for black students. Similarly, in grade 8, scores improved by 8 and 5 points for Hispanic and black students, respectively, compared with a 3-point gain for white students.

Sex. The average mathematics scores for male fourth graders and twelfth graders were slightly higher than the average scores for female students in those grades: 241 for male versus 239 for female fourth graders, and 153 for male versus 150 for female twelfth graders. There was no difference in scores by sex for eighth graders because female students at this grade level gained more points (4 since 2005) in the past decade than male students did (2 since 2005).

Socioeconomic status and sex by race or ethnicity. Score differences between students who were eligible for free or reduced-price lunch (low SES) and those who were not eligible (high SES) were observed within racial or ethnic groups in 2015. For example, the gaps between eligible and non-eligible students in grade 4 were 25 points among Asian or Pacific Islander students, 18 points among white students, 17 points among Hispanic students, and 16 points among black students (Table 1-2). Similar gaps held among eighth and twelfth grade students, except for a smaller 9-point gap among Hispanic students in grade 12.

A few small differences in average mathematics scores by sex were observed in 2015 within racial or ethnic groups (Table 1-2). In grade 4, the average score for white male students was 2 points higher than the score for white female students. Among black students in grade 4, the pattern was reversed, with the average score for black female students 2 points higher than the score for black male students. The average score for black female students was also higher than that for black male students in grade 8, although there was no significant difference by sex at grade 12. The largest difference in average scores for male and female students was among Hispanic students in grade 12. The average score for male students was 5 points higher than that for female students.

TABLE 1-2

Average scores of students in grades 4, 8, and 12 on the main NAEP mathematics assessment, by socioeconomic status and sex within race or ethnicity: 2015

(Average score)

Grade and race or ethnicity	Socioeconomic status[a]		Sex	
	Eligible for free or reduced-price lunch	Not eligible for free or reduced-price lunch	Male	Female
All students in grade 4				
White	237	255	249	247
Black	221	237	223	225
Hispanic[b]	227	244	231	229
Asian or Pacific Islander	241	266	259	255
American Indian or Alaska Native	223	239	228	226
More than one race	233	256	246	244
All students in grade 8				
White	276	298	292	291
Black	256	273	259	262
Hispanic[b]	266	282	270	270
Asian or Pacific Islander	291	316	305	306
American Indian or Alaska Native	260	280	265	270
More than one race	271	296	285	285
All students in grade 12				
White	145	164	161	159
Black	124	140	129	131
Hispanic[b]	135	144	141	136
Asian or Pacific Islander	157	177	171	169
American Indian or Alaska Native	133	s	141	s
More than one race	144	165	158	157

s = suppressed for reasons of confidentiality and/or reliability.

NAEP = National Assessment of Educational Progress.

[a] NAEP uses eligibility for the federal National School Lunch Program (NSLP) as a measure of socioeconomic status. NSLP is a federally assisted meal program that provides low-cost or free lunches to eligible students. It is sometimes referred to as the free or reduced-price lunch program.

[b] Hispanic may be any race. American Indian or Alaska Native, Asian or Pacific Islander, black, white, and more than one race refer to individuals who are not of Hispanic origin.

Note(s)

Main NAEP mathematics assessment scores range from 0 to 500 for grades 4 and 8 and from 0 to 300 for grade 12.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2016) of main NAEP 2015 mathematics assessment, National Center for Education Statistics.

Science and Engineering Indicators 2018

Proficiency level. Forty percent of fourth graders, 33% of eighth graders, and 25% of twelfth graders achieved a level of proficient or higher in mathematics in 2015 (Appendix Table 1-2). As with average scale scores, these percentages represent slight decreases compared with 2013 for fourth and eighth graders but are slight increases since 2005. In the decade since 2005, the percentage of students scoring proficient or above increased by about 4 percentage points for fourth graders and 3 percentage points for eighth graders. In the period between 1996 and 2005, the increases were larger: about 15 percentage points for students in grade 4, and 7 percentage points for students in grade 8. Although the percentage of students reaching proficiency or better did increase, on average, it stayed well below 50% for all grade levels and decreased as the grade level increased.

Demographic patterns similar to those noted in the discussion of scale scores also characterized the proficiency levels. For example, 51% of grade 4 white and 62% of grade 4 Asian or Pacific Islander students reached proficiency in mathematics (Appendix Table 1-2). The percentages for grade 4 students in other racial or ethnic groups were much lower: 26% for Hispanic students, 23% for American Indian or Alaska Native students, and 19% for black students.

Science Performance of Students in Grades 4, 8, and 12 in 2015

Average score. The average NAEP science scores of students in 2015 were 154 for fourth and eighth graders and 150 for twelfth graders (Appendix Table 1-3). Although the overall scale for the assessments is 0 to 300, the effective score range of these tests is about 90 points: 80% of fourth graders scored between 108 and 196, 80% of eighth graders scored between 109 and 195, and 80% of twelfth graders scored between 103 and 196. The average NAEP science scores increased 4 points between 2009 and 2015 in grades 4 and 8 but did not change for grade 12.

Socioeconomic status. Students who were not eligible for free or reduced-price lunch (high SES) performed better than eligible (low SES) students at all grade levels (Appendix Table 1-3). For example, the gap between non-eligible and eligible fourth graders in 2015 was 29 points. Among eighth graders, the gap was 27 points, and twelfth graders had a gap of 26 points. The gap between non-eligible and eligible students did not decrease significantly between 2009 and 2015 for any grade level.

Race or ethnicity. As with mathematics, average science scores varied by race or ethnicity at all grade levels, with Asian or Pacific Islander and white students scoring 10–16 points above the average score, and black, Hispanic, and American Indian or Alaska Native students scoring 14–25 points below (Appendix Table 1-3). The gaps between the scores of white and black students and between those of white and Hispanic students have narrowed slightly since 2009 in grades 4 and 8 but not in grade 12.

Sex. There were no sex differences in average science scores for students in grade 4 in 2015 (Appendix Table 1-3). However, average scores for male students were higher than scores for female students by 3 points in grade 8 and by 5 points in grade 12. The gap between male and female students in grade 8 narrowed slightly from 5 points in 2011 to 3 points in 2015. The gap in science scores in grade 12 has not narrowed significantly since 2009.

Socioeconomic status and sex by race or ethnicity. There were substantial differences by SES within all racial or ethnic groups and at all grade levels (▦ Table 1-3). For example, gaps between twelfth graders who were eligible for free or reduced-price lunch and those who were not eligible ranged from 13 points for Hispanic students to 27 points for Asian or Pacific Islander students. Average science scores showed some variation by sex within racial or ethnic groups, although, in many cases, differences between male and female students were not significant. The largest difference was among Hispanics in grades 8 and 12, with male students earning higher average scores than female students by 5 points in grade 8 and 7 points in grade 12.

Proficiency level. In 2015, 38% of fourth graders, 34% of eighth graders, and 22% of twelfth graders achieved a level of proficient or higher on the NAEP science assessment (Appendix Table 1-4). The percentage of fourth and eighth grade students scoring at or above the proficient level increased by 4 points since 2009. The percentage of twelfth graders scoring at or above the proficient level did not change significantly during that same period.

TABLE 1-3

Average scores of students in grades 4, 8, and 12 on the main NAEP science assessment, by socioeconomic status and sex within race or ethnicity: 2015

(Average score)

Grade and race or ethnicity	Socioeconomic status[a]		Sex	
	Eligible for free or reduced-price lunch	Not eligible for free or reduced-price lunch	Male	Female
All students in grade 4				
White	154	172	166	165
Black	129	148	132	134
Hispanic[b]	134	157	139	139
Asian or Pacific Islander	150	178	168	166
American Indian or Alaska Native	134	158	139	140
More than one race	147	171	157	159
All students in grade 8				
White	153	171	167	164
Black	127	146	131	132
Hispanic[b]	135	154	142	137
Asian or Pacific Islander	148	174	165	164
American Indian or Alaska Native	134	155	142	136
More than one race	146	170	161	158
All students in grade 12				
White	146	164	162	159
Black	119	136	127	123
Hispanic[b]	132	145	140	133
Asian or Pacific Islander	150	177	167	165
American Indian or Alaska Native	s	s	s	s
More than one race	145	162	160	151

s = suppressed for reasons of confidentiality and/or reliability.

NAEP = National Assessment of Educational Progress.

[a] NAEP uses eligibility for the federal National School Lunch Program (NSLP) as a measure of socioeconomic status. NSLP is a federally assisted meal program that provides low-cost or free lunches to eligible students. It is sometimes referred to as the free or reduced-price lunch program.

[b] Hispanic may be any race. American Indian or Alaska Native, Asian or Pacific Islander, black, white, and more than one race refer to individuals who are not of Hispanic origin.

Note(s)

Main NAEP science assessment scores range from 0 to 300 for grades 4, 8, and 12.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2016) of main NAEP 2015 science assessment, National Center for Education Statistics.

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Technology and Engineering Performance of Students in Grade 8 in 2014

The NAEP TEL assessment is the newest addition to NAEP assessment tests. It was first administered in winter 2014 to a nationally representative sample of eighth graders. Rather than testing students for their ability to “do” engineering or produce technology, TEL was designed to gauge how well students can apply their understanding of technology principles to real-life situations. TEL departs from the typical NAEP assessment design because it is completely computer based and includes interactive scenario-based tasks—an innovative component of NAEP (see sidebar About the NAEP Technology and Engineering Literacy Assessment).

SIDEBAR

About the NAEP Technology and Engineering Literacy Assessment

The National Assessment Governing Board (NAGB) is an independent, bipartisan organization that oversees the National Assessment of Educational Progress (NAEP). Because of the growing importance of technology and engineering in the educational landscape, and to support America's ability to contribute to and compete in a global economy, NAGB set out in 2008 to develop a framework for a national assessment of students' knowledge and skills in technology and engineering (NAGB 2013). NAGB solicited input for the framework from technology and engineering experts, business leaders, educational policymakers, teachers, parents, and the public via regional forums, webinars, and committee meetings to draft and refine the NAEP technology and engineering literacy (TEL) framework. The framework describes the specific knowledge and skills to be assessed and how the assessment questions should be designed and scored. In the framework, technology is defined as "any modification of the natural world done to fulfill human needs or desires" and engineering is "a systematic and often iterative approach to designing objects, processes, and systems to meet human needs and wants" (NAGB 2013:xi). The framework defines technological and engineering literacy as "the capacity to use, understand, and evaluate technology as well as to understand technological principles and strategies needed to develop solutions and achieve goals" (NAGB 2013:xi).

The first completely computer-based NAEP assessment, TEL includes interactive scenario-based tasks in addition to more traditional short-answer and multiple-choice questions.[*] Using videos and interactive graphics, scenario-based tasks ask students to demonstrate their knowledge and skills to solve problems within realistic situations. For example, one task requires students to develop an online exhibit on water pollution, whereas other tasks require students to design a safe bike lane or create an ideal iguana habitat. Each scenario includes several questions and takes between 10 and 30 minutes to complete. These scenario-based tasks are designed to measure three major interconnected content areas—Technology and Society, Design and Systems, and Information and Communication Technology—and three practices that cut across the content areas—Understanding Technological Principles, Developing Solutions and Achieving Goals, and Communicating and Collaborating. Some tasks measure students' abilities in one content area and practice, and other tasks measure more than one content area or practice.

TEL was piloted in 2013 and administered to 21,500 students in approximately 840 public and private schools around the country in 2014. The National Center for Education Statistics, which administers NAEP, brought its own Internet service and laptop computers into schools to avoid any technical difficulties associated with administering computer-based assessments in classrooms. Before the assessment began, students viewed a tutorial that helped them become familiar with the computer interface and how to use the assessment program.

[*] All NAEP exams were digitally administered as of 2017.

The average TEL score was set to 150 out of 300 as a baseline for future comparisons, and 43% of test takers scored at or above the proficient level (Appendix Table 1-5).

Socioeconomic status. Scores on the TEL varied considerably by school lunch eligibility, with the average score for eligible students nearly 30 points below that of non-eligible students. The percentage of non-eligible students scoring at or above the proficient level (59%) was more than double the percentage of eligible students scoring at that level (25%).

Race or ethnicity. The average scores for Asian or Pacific Islander (159) and white (160) students were higher than the average scores for Hispanic (138) and black (128) students. More than half of Asian or Pacific Islander and white students scored at or above the proficient level, compared with 28% of Hispanic students and 18% of black students.

Sex. Female students had an average score of 151, which was slightly higher than male students' average score of 149. A slightly higher percentage of female than male students scored at or above the proficient level (45% versus 42%).

Socioeconomic status and sex by race or ethnicity. Some sex and school-lunch eligibility differences in TEL achievement were observed within racial or ethnic groups (▦Table 1-4). Within each racial or ethnic group, students who were eligible for free or reduced-price lunch had average scores at least 19 points lower than non-eligible students. The average score for white female students was slightly higher than the average for white male students, and the same held true for black female and male students.

TABLE 1-4 ▦

Average scores of students in grade 8 on the main NAEP technology and engineering literacy assessment, by socioeconomic status and sex within race or ethnicity: 2014

(Average score)

Race or ethnicity	Socioeconomic status[a]		Sex	
	Eligible for free or reduced-price lunch	Not eligible for free or reduced-price lunch	Male	Female
White	145	166	158	162
Black	122	144	126	131
Hispanic[b]	133	152	137	139
Asian or Pacific Islander	144	171	159	159
American Indian or Alaska Native	137	s	s	s
More than one race	143	163	149	160

s = suppressed for reasons of confidentiality and/or reliability.

NAEP = National Assessment of Educational Progress.

[a] NAEP uses eligibility for the federal National School Lunch Program (NSLP) as a measure of socioeconomic status. NSLP is a federally assisted meal program that provides low-cost or free lunches to eligible students. It is often referred to as the free or reduced-price lunch program.

[b] Hispanic may be any race. American Indian or Alaska Native, Asian or Pacific Islander, black, white, and more than one race refer to individuals who are not of Hispanic origin.

Note(s)

Main NAEP technology and engineering literacy assessment scores range from 0 to 300.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2016) of main NAEP 2014 technology and engineering literacy assessment, National Center for Education Statistics.

Science and Engineering Indicators 2018

State-Level Performance in Mathematics and Science in 2015

In addition to reporting NAEP achievement at the national level, NAEP also reports achievement at the state level. The NAEP sample in each state is designed to be representative of the students in that state, and results can be compared across states. At the state level, results are reported for public school students only and are broken down by several demographic groupings. In this chapter, we present 2015 NAEP state-level data (average scores and percentages reaching proficient or above) broken out by sex and race or ethnicity for fourth and eighth graders in mathematics and science (Appendix Table 1-6 through Appendix Table 1-13). The *Science and Engineering Indicators* State Indicators data tool provides NAEP performance and proficiency data for all students in each state—not broken out by sex, race, or ethnicity.

Mathematics and Science Knowledge in Early Childhood

ECLS-K:2011 is a nationally representative, longitudinal study of children's development, early learning, and school progress (Mulligan, Hastedt, and McCarroll 2012). Data for the ECLS-K:2011 study were first collected in fall 2010 from approximately 18,200 kindergarten students. ECLS-K:2011 has followed and tested the same student sample each year through spring 2016, when most students were in fifth grade. This section provides information about mathematics and science achievement for children in the ECLS-K:2011 cohort who were in kindergarten for the first time in the 2010–11 school year and in the third grade by the spring of 2014. It compares students' mathematics scores from the beginning of kindergarten to the end of third grade and students' science scores from the beginning of first grade to the end of third grade. Science was not assessed in kindergarten. Results are reported as scale scores and are used here for comparative purposes rather than as indicators of student progress in meeting grade-level objectives. Students' mathematics and science assessment results cannot be compared with each other because scales are developed independently for each subject. The possible range of scores for the third grade mathematics assessment in spring 2014 was 0–135, with an actual range of scores of 39–133 and an overall average score of 99 (▦ Table 1-5; Appendix Table 1-14). The possible range of scores for the third grade science assessment in spring 2014 was 0–87, with an actual range of scores of 21–78 and an overall average score of 56 (Appendix Table 1-15).

TABLE 1-5

Average mathematics and science assessment test scores of children who were in kindergarten for the first time during the 2010–11 school year and in third grade during the 2013–14 school year, by child and family characteristics

(Average score)

Child and family characteristic	Mathematics		Science	
	Fall 2010	Spring 2014	Fall 2011[a]	Spring 2014
All children	29.3	99.2	23.9	55.6
Sex				
Male	29.4	100.9	23.9	56.3
Female	29.2	97.4	23.9	55.0
Race or ethnicity[b]				
White	31.7	102.9	26.0	58.5
Black	25.8	90.2	21.0	50.0
Hispanic[c]	24.7	94.3	20.5	51.5
Asian	34.5	104.3	23.4	57.5
American Indian or Alaska Native	26.3	99.2	24.7	54.3
Family poverty status in fall 2010[d]				
Income below the federal poverty level	24.1	93.3	20.7	51.0
Income at or above 200% of the federal poverty level	33.3	103.2	25.9	58.9

[a] There was no science assessment in academic year 2010–11. Science assessment began in grade 1.

[b] Other racial and ethnic groups are included in all children but are not shown separately in the table.

[c] Hispanic may be any race. American Indian or Alaska Native, Asian, black, and white refer to individuals who are not of Hispanic origin.

[d] Poverty status is based on 2010 U.S. Census poverty thresholds, which identify incomes determined to meet household needs, given family size. For example, in 2010, a family of two was below the poverty threshold if its income was lower than $14,220.

Note(s)

Mathematics was first assessed in kindergarten in fall 2010. Science was first assessed in first grade in fall 2011. The mathematics assessment scale was 0 to 75 in kindergarten and 0 to 135 in third grade. The actual score range in third grade was 39 to 133. The science assessment scale was 0 to 47 in first grade and 0 to 87 in third grade. The actual score range in third grade was 21 to 78.

Source(s)

Mulligan GM, Hastedt S, McCarroll JC, *First-Time Kindergartners in 2010–11*: *First Findings From the Kindergarten Rounds of the Early Childhood Longitudinal Study, Kindergarten Class of 2010–11 (ECLS-K:2011)*, NCES 2012-049 (2012); Mulligan GM, McCarroll JC, Flanagan KD, Potter D, *Findings From the First-Grade Rounds of the Early Childhood Longitudinal Study, Kindergarten Class of 2010–11 (ECLS-K: 2011)*, NCES 2015-109 (2014); Mulligan GM, McCarroll JC, Flanagan KD, Potter D, *Findings From the Third-Grade Round of the Early Childhood Longitudinal Study, Kindergarten Class of 2010–11 (ECLS-K:2011),* NCES 2016-094 (2016). See Appendix Table 1-14 and Appendix Table 1-15.

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Socioeconomic status. In spring of third grade, the average score for students in families with income at or above 200% of the federal poverty level was 10 points higher on the mathematics assessment and 8 points higher on the science assessment than for students in families with income below the federal poverty level.

Race or ethnicity. Asian students achieved an average score of 104 on the mathematics assessment at the end of third grade, followed by white (103), Hispanic (94), and black (90) students (Table 1-5). Science assessment scores followed a similar pattern, except that white students (59) earned a slightly higher average score than Asian students (58). In mathematics, black students (26) and Hispanic students (25) earned similar average scores when entering kindergarten, but this pattern reversed by third grade, with Hispanic students earning higher average scores than black students (94 versus 90, respectively). A similar pattern was seen in science.

Sex. ECLS-K:2011 data revealed achievement gaps between male and female students (see sidebar Early Gender Gaps in Mathematics and Teachers' Perceptions). Although they began kindergarten with the same average scale score in mathematics (29), the average score for male students was higher than for female students by the end of third grade (101 versus 97) (Table 1-5). Science scores showed a similar pattern, with male and female students posting the same average score in first grade (24) and male students slightly outscoring female students by the end of third grade (56 versus 55).

SIDEBAR

Early Gender Gaps in Mathematics and Teachers' Perceptions

Women are appreciably underrepresented in many high-paying science, technology, engineering, and mathematics (STEM) fields (National Science Foundation [NSF] 2017). Early achievement and self-concepts may matter for STEM career paths. For example, grade 12 mathematics achievement and mathematics self-concepts influence eventual STEM career choices (Eccles and Wang 2016; Mann and DiPrete 2013).

In their examination of Early Childhood Longitudinal Study, Kindergarten (ECLS-K) data from two longitudinal series beginning in 1999 and 2011, Cimpian and colleagues (2016) found that gender gaps in mathematics worsen in early education and that teachers misperceive girls' mathematics ability. ECLS-K data have advantages over other data sources because they use computerized adaptive testing—in which the test questions become progressively easier or harder based on how students are performing on the test. Such testing more accurately discerns student ability at various points on the ability spectrum, particularly the extremes.

Cimpian and colleagues found that, for the 2011 cohort, about equal numbers of boys and girls scored below the 85th percentile in mathematics achievement upon entry into kindergarten. Above the 85th percentile, however, there were fewer girls than boys: girls made up 45% of all those above the 85th percentile and only 33% of those above the 99th percentile. The gender gap worsened and spread further down the distribution with more schooling. By the spring of second grade, the most recent data available to the researchers, male students were favored at all points above the 15th percentile, and female students constituted only 20% of those above the 99th percentile. Examining students with comparable demographic characteristics, learning behaviors, and past mathematics achievement does not remove gender gaps throughout the distribution.

The authors found virtually no significant differences between the 1999 and 2011 cohorts. There were a few percentile points in the upper range of the distribution in which boys were doing better than girls in 2011, but otherwise, there were no differences. This suggests that efforts to improve mathematics education during this time did not lift the relative performance of female students.

This study also asked teachers to give their subjective estimation of every student's proficiencies in various mathematical skills, which were then converted to single scores that were ranked among all students to yield each student's percentile (e.g., student x is at the 90th percentile in mathematical ability). For each student, this subjective percentile was then directly compared with the student's actual percentile. For the 2011 cohort, the study found that teachers' subjective ratings of mathematical proficiency underestimate the proficiency of girls at the higher end of the ability spectrum, above the 75th percentile, by the spring of first grade. Robinson-Cimpian and colleagues (2014) present evidence that teachers' more negative perceptions of girls' proficiency are substantially related to their future performance.

Achievement gap over time. The ECLS-K:2011 mathematics and science results show that students from different racial, ethnic, and socioeconomic groups enter school with different levels of preparation and that those differences persist as they move to higher grades, a finding that is supported in the research literature (Loeb and Bassok 2007; Magnuson and Duncan 2006). For example, the gap in mathematics assessment scores between white and black students was 6 points at the beginning of kindergarten and 13 points in the spring of third grade (Table 1-5). Similarly, the gap in science assessment scores between white and black students was 5 points at the beginning of first grade and 9 points in the spring of third grade. The mathematics score gap between students in families with income below the federal poverty level and those in families with income at or above 200% of the federal poverty level was 9 points at the beginning of kindergarten and 10 points by the spring of third grade (📊Figure 1-2); the science score gap was 5 points at the beginning of first grade and 8 points by the spring of third grade.

FIGURE 1-2

Average mathematics assessment test scores of children who were in kindergarten for the first time during the 2010–11 school year and in the third grade during the 2013–14 school year, by family income level

Note(s)

The mathematics assessment scale was 0 to 75 in kindergarten, 0 to 96 in first grade, 0 to 113 in second grade, and 0 to 135 in third grade. Mathematics was assessed in the fall and spring of each school year with the exception of third grade when students were assessed only in the spring. Poverty status is based on 2010 U.S. Census poverty thresholds, which identify incomes determined to meet household needs, given family size. For example, in 2010, a family of two was below the poverty threshold if its income was lower than $14,220.

Source(s)

Mulligan GM, Hastedt S, McCarroll JC, *First-Time Kindergartners in 2010–11*: *First Findings From the Kindergarten Rounds of the Early Childhood Longitudinal Study, Kindergarten Class of 2010–11 (ECLS-K:2011)*, NCES 2012-049 (2012); Mulligan GM, McCarroll JC, Flanagan KD, Potter D, *Findings From the First-Grade Rounds of the Early Childhood Longitudinal Study, Kindergarten Class of 2010–11 (ECLS-K:2011)*, NCES 2015-109 (2014); Mulligan GM, McCarroll JC, Flanagan KD, Potter D, *Findings From the Second-Grade Rounds of the Early Childhood Longitudinal Study, Kindergarten Class of 2010–11 (ECLS-K:2011)*, NCES 2015-077 (2015); and Mulligan GM, McCarroll JC, Flanagan KD, Potter D, *Findings From the Third-Grade Round of the Early Childhood Longitudinal Study, Kindergarten Class of 2010–11 (ECLS-K:2011)*, NCES 2016-094 (2016).

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International Comparisons of Mathematics and Science Performance

Two international assessments—the Trends in International Mathematics and Science Study (TIMSS) and the Program for International Student Assessment (PISA)—compare U.S. students' achievement in mathematics and science with that of students in other countries. TIMSS and PISA give different impressions of the United States' standing relative to other countries, with TIMSS results placing the United States in a higher relative position compared with PISA. This disparity can be traced, in part, to differences in the design and purpose of the assessments. TIMSS focuses on academic content, whereas PISA is designed to measure students' ability to apply their mathematics and science knowledge to real-world situations. The two tests also vary in other fundamental ways, including age of the students tested and number of participating nations, making direct comparisons difficult. TIMSS and PISA have sampling requirements to ensure that student populations are similar across countries and report when countries do not meet these guidelines. TIMSS and PISA samples include students from public and private schools in the United States. This section presents an overview of each assessment, examines long-term trends in performance on both assessments, and provides a detailed look at the latest data from 2015.

The Trends in International Mathematics and Science Study

TIMSS includes two assessments: TIMSS for students in grades 4 and 8 and TIMSS Advanced for students in their final year of high school. First conducted in 1995, TIMSS assesses the mathematics and science performance of fourth and eighth graders every 4 years. Since its inception, TIMSS has been administered six times, most recently in 2015, when 20,000 fourth and eighth grade students in approximately 500 schools across the United States participated (Provasnik et al. 2016).[4] TIMSS Advanced was administered in 1995, 2008, and 2015. It is designed to assess the advanced mathematics and physics achievement of students in their final year of high school who are taking or have taken advanced courses.[5] The United States participated in the 1995 and 2015 administrations.

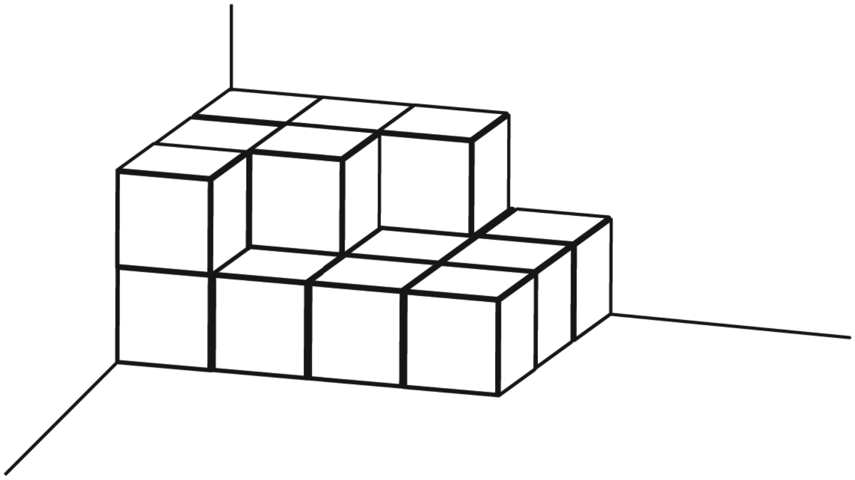
TIMSS and TIMSS Advanced measure students' knowledge and skills in mathematics and science and their ability to apply their knowledge in problem-solving situations. Both are designed to align broadly with mathematics and science curricula in the participating education systems and, therefore, to reflect students' school-based learning. At each grade, students respond to multiple-choice and constructed-response items (or questions) designed to measure what they know and can do across specific content domains in mathematics and science (see sidebar Sample Items from the Trends in International Mathematics and Science Study 2015).

SIDEBAR

Sample Items from the Trends in International Mathematics and Science Study 2015

The examples shown below and other mathematics and science sample questions are available at https://timssandpirls.bc.edu/timss2015/downloads/T15_FW_AppB.pdf and https://timssandpirls.bc.edu/timss2015/downloads/T15_FW_AppC.pdf, respectively.

Sample for Grade 4 Mathematics



Ann stacks these boxes in the corner of the room. All the boxes are the same size. How many boxes does she use?

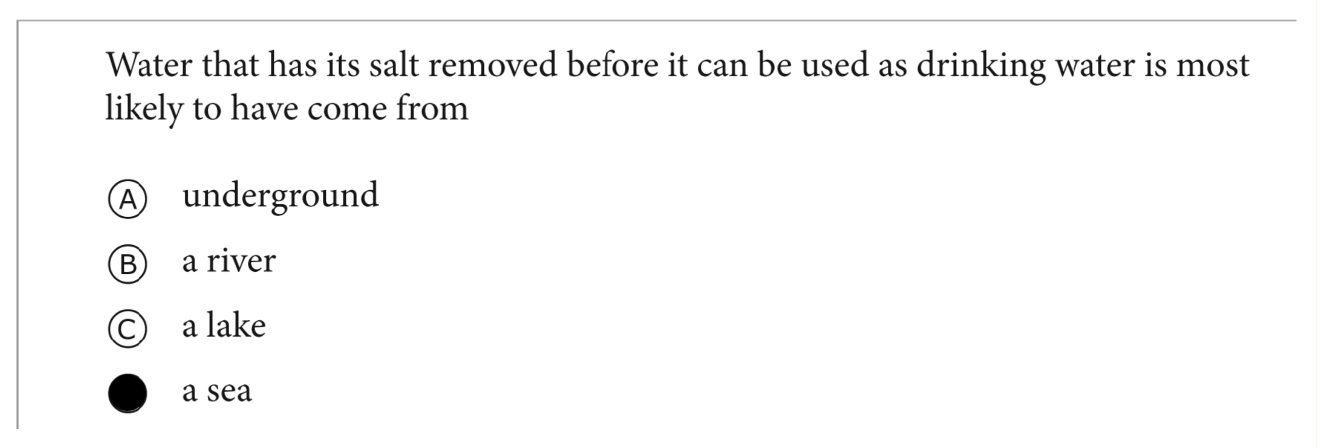
Ⓐ 25

Ⓑ 19

● 18

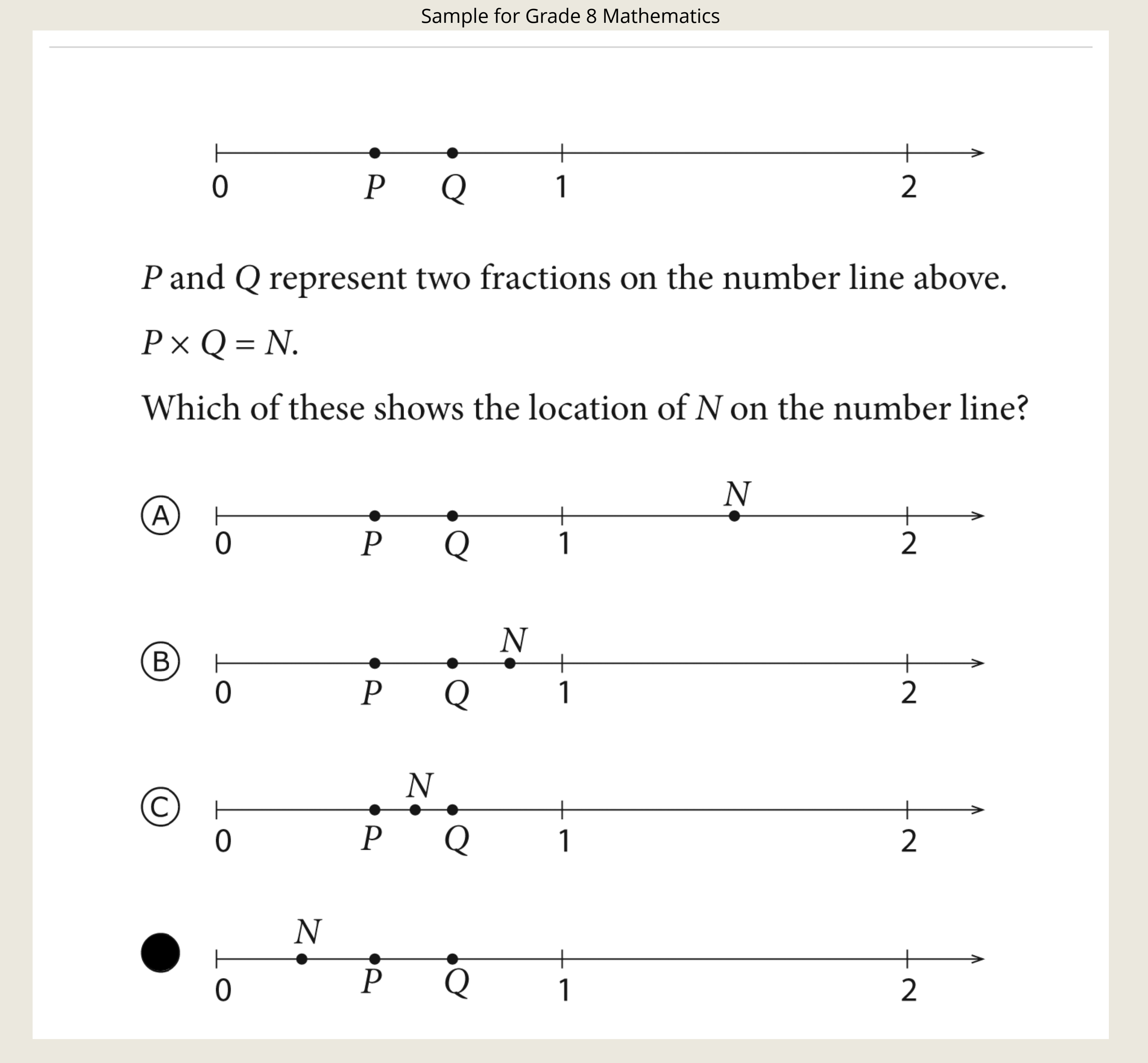
Ⓓ 13

Sample for Grade 4 Science



Water that has its salt removed before it can be used as drinking water is most likely to have come from

Ⓐ underground
Ⓑ a river
Ⓒ a lake
● a sea



Sample for Grade 8 Mathematics

P and *Q* represent two fractions on the number line above.

$P \times Q = N$.

Which of these shows the location of *N* on the number line?

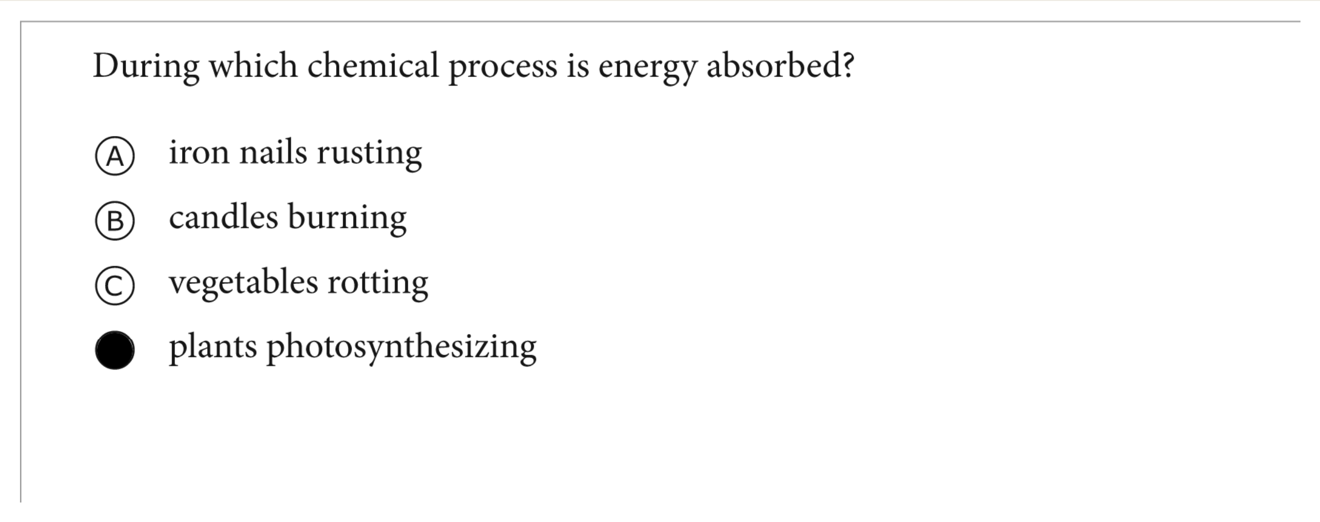
Ⓐ

Ⓑ

Ⓒ

●

Sample for Grade 8 Science



During which chemical process is energy absorbed?

Ⓐ iron nails rusting
Ⓑ candles burning
Ⓒ vegetables rotting
● plants photosynthesizing

TIMSS and TIMSS Advanced are both sponsored by the International Association for the Evaluation of Educational Achievement (IEA), an international, nonprofit organization consisting of research institutions and government research agencies from member countries and economies. In 2015, 48 IEA member countries or economies and 6 benchmarking participants[6] took part in the grade 4 assessment, and 37 IEA member countries and 6 benchmarking participants took part in the grade 8 assessment.[7] Nine education systems—all IEA member countries—participated in TIMSS Advanced 2015. IEA member countries include "countries," which are complete, independent political entities, and non-national entities (e.g., England, Hong Kong, or the Flemish community of Belgium). The term *education systems* is used in the analysis here in recognition of the fact that not all TIMSS participants are countries, and this fact should be kept in mind when comparing the performance of the United States and that of other education systems.

Mathematics Performance of U.S. Students in Grades 4 and 8 on TIMSS

Performance on the 2015 TIMSS mathematics tests. The U.S. average score on the 2015 TIMSS mathematics assessment was 539 for grade 4 and 518 for grade 8 (Table 1-6).[8] Although the scale is 0–1,000 for both grades, the effective score range of these tests for the preponderance of American students is about 200 points. Eighty percent of fourth graders scored between 432 and 640; for grade 8, it was between 408 and 624. Among the 48 education systems that participated in the 2015 TIMSS mathematics assessment at grade 4, the U.S. average mathematics score was among the top 18 (10 scored higher; 7 did not differ), outperforming 30 education systems (Appendix Table 1-16).[9] At grade 8, the U.S. average mathematics score was among the top 16 (7 scored higher; 8 did not differ), outperforming 21 education systems. (Appendix Table 1-17). The same 5 Asian education systems—Singapore, Hong Kong, South Korea, Taiwan, and Japan—were the top scorers on the fourth and eighth grade assessments. All 5 outscored the United States by at least 50 points (Table 1-7).

TABLE 1-6

Average TIMSS mathematics scores of U.S. students in grades 4 and 8, by selected student and school characteristics: 2015

(Average score)

Characteristic	Grade 4	Grade 8
U.S. total	539	518
Sex		
Male	543	519
Female	536	517
Race or ethnicity		
White	559	541
Black	495	462
Hispanic	515	492
Asian	605	585
Native Hawaiian or Pacific Islander	502	495
American Indian or Alaska Native	527	477
Multiracial	565	521
Percentage of public school students eligible for free or reduced-price lunch		
Less than 10%	600	573
10% to 24.9%	575	553
25% to 49.9%	559	531
50% to 74.9%	531	505
75% or more	499	477
Percentiles		
10th percentile	432	408
25th percentile	485	461
75th percentile	596	577
90th percentile	640	624

TIMSS = Trends in International Mathematics and Science Study.

Note(s)

Black includes African American, and Hispanic includes Latino. Racial categories exclude Hispanic origin. Data on free or reduced-price lunch are for public schools only.

Source(s)

Provasnik S, Malley L, Stephens M, Landeros K, Perkins R, Tang JH, *Highlights from TIMSS and TIMSS Advanced 2015: Mathematics and Science Achievement of U.S. Students in Grades 4 and 8 and in Advanced Courses at the End of High School in an International Context*, NCES 2017-002 (2016); U.S. Department of Education, National Center for Education Statistics, TIMSS data tables, Table 19. Average mathematics scores of U.S. 4th-grade students, by selected characteristics: 2015, https://nces.ed.gov/timss/timss2015/timss2015_table19.asp, accessed 15 September 2017, and Table 20. Average mathematics scores of U.S. 8th-grade students, by selected characteristics: 2015, https://nces.ed.gov/timss/timss2015/timss2015_table20.asp, accessed 15 September 2017.

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TABLE 1-7

Average TIMSS mathematics scores of students in grades 4 and 8, by education system: 2015

(Average score)

Comparison with U.S. score	Education system	Grade 4	Education system	Grade 8
Score higher than that of the United States	Singapore[a]	618	Singapore[a]	621
	Hong Kong (China)[a]	615	South Korea	606
	South Korea	608	Taiwan (China)	599
	Taiwan (China)	597	Hong Kong (China)	594
	Japan	593	Japan	586
	Northern Ireland (UK)[a]	570	Russia	538
	Russia	564	Canada[a]	527
	Norway (grade 5)[a]	549		
	Ireland	547		
	Belgium (Flemish)[a]	546		
Score not statistically different from that of the United States	England (UK)	546	Kazakhstan	528
	Kazakhstan	544	Ireland	523
	Portugal[a]	541	United States[a]	518
	United States[a]	539	England (UK)	518
	Denmark[a]	539	Slovenia	516
	Lithuania[a]	535	Hungary	514
	Finland	535	Norway (grade 9)[a]	512
	Poland	535	Lithuania[a]	511
			Israel[a]	511

Comparison with U.S. score	Education system	Grade 4	Education system	Grade 8
Score lower than that of the United States (selected countries)	Netherlands[a]	530	Australia	505
	Hungary	529	Sweden	501
	Czech Republic	528	Italy[a]	494
	Bulgaria	524	Malta	494
	Cyprus	523	New Zealand[a]	493
	Germany	522	Malaysia	465
	Slovenia	520	United Arab Emirates	465
	Sweden[a]	519	Turkey	458
	Serbia[a]	518	Bahrain	454
	Australia	517	Georgia[a]	453

TIMSS = Trends in International Mathematics and Science Study; UK = United Kingdom.

[a] See Appendix Table 1-16 and Appendix Table 1-17 for details about TIMSS administration in these education systems.

Note(s)

Education systems are ordered by the 2015 average score. The countries shown in the Score lower than that of the United States section are the 10 with the highest average scores below the United States.

Source(s)

Provasnik S, Malley L, Stephens M, Landeros K, Perkins R, Tang JH, *Highlights from TIMSS and TIMSS Advanced 2015: Mathematics and Science Achievement of U.S. Students in Grades 4 and 8 and in Advanced Courses at the End of High School in an International Context*, NCES 2017-002 (2016).

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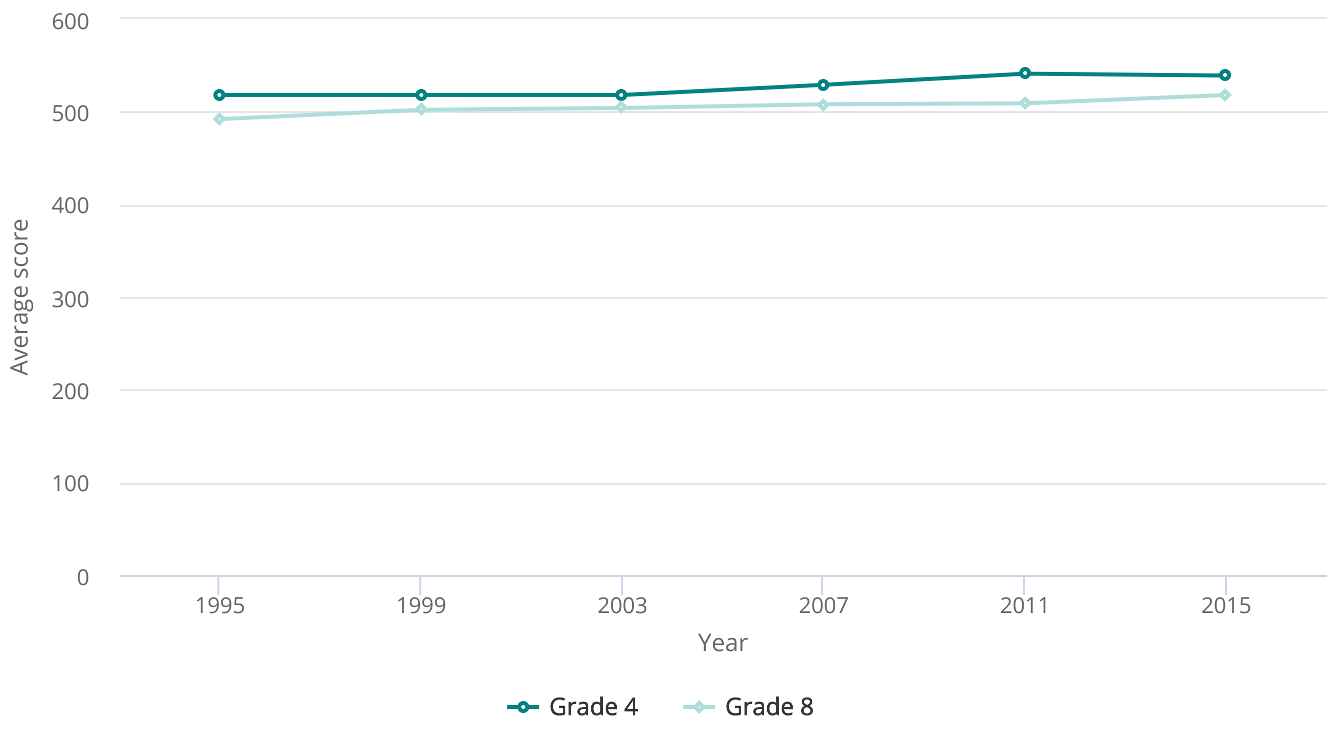
Performance trends. U.S. fourth and eighth graders have raised their scores and international ranking over the 20 years since the first TIMSS mathematics administration in 1995. At grade 4, the average mathematics score of 539 in 2015 was 21 points higher than the score of 518 in 1995 (Figure 1-3), although the 2015 average score was not significantly different from the most recent assessment in 2011 (541). The position of U.S. fourth graders relative to other nations climbed as well over this period: among the 16 education systems that participated in the 1995 and 2015 TIMSS mathematics assessment of fourth graders, 7 outscored the United States in 1995 compared with 5 in 2015 (Provasnik et al. 2016). At grade 8, the U.S. average score of 518 in 2015 reflected a 26-point increase over the 1995 score of 492 and an increase of 9 points since the most recent assessment in 2011 (509) (Figure 1-3). The relative standing of U.S. eighth graders' mathematics performance also improved over this period: among the 15 countries that participated in the 1995 and 2015 TIMSS mathematics assessment of eighth graders, 5 outperformed the United States in 2015, down from 8 in 1995 (Provasnik et al. 2016).

FIGURE 1-3

Average TIMSS mathematics scores of U.S. students in grades 4 and 8: 1995–2015



TIMSS = Trends in International Mathematics and Science Study.

Note(s)

TIMSS mathematics assessment scores range from 0 to 1,000 for grades 4 and 8. U.S. fourth graders did not participate in TIMSS in 1999; score is interpolated. Average mathematics scores of students in grade 4 and grade 8 cannot be compared directly because the test items differ across grade levels to reflect the nature, difficulty, and emphasis of the subject matter taught in school at each grade.

Source(s)

Provasnik S, Malley L, Stephens M, Landeros K, Perkins R, Tang JH, *Highlights From TIMSS and TIMSS Advanced 2015: Mathematics and Science Achievement of U.S. Students in Grades 4 and 8 and in Advanced Courses at the End of High School in an International Context*, NCES 2017-002 (2016).

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Demographic differences. U.S. scores in 2015 differed according to the percentage of students eligible for free or reduced-price lunch at participants' schools (Table 1-6). Students at schools with less than 10% of eligible students scored approximately 100 points higher than students at schools with 75% or more eligible students in fourth (600 versus 499) and eighth (573 versus 477) grade. In 2015, the average mathematics assessment score for male fourth graders (543) was higher than the average score for female fourth graders (536), but there was no statistically significant difference in average scores for male and female eighth graders. The average score for grade 4 Asian students (605) was significantly higher than that for white students (559), and both were significantly higher than the average scores for Hispanic (515) and black (495) students. A similar pattern was seen among grade 8 students.

Science Performance of U.S. Students in Grades 4 and 8 on TIMSS

Performance on the 2015 TIMSS science tests. In 2015, the U.S. average science scores were 546 for fourth graders and 530 for eighth graders (▦ Table 1-8). As with mathematics, the effective score range for most students was about 200 points, with 80% of fourth graders scoring between 439 and 644 and 80% of eighth graders scoring between 421 and 631. At grade 4, the United States was among the top 14 education systems (7 scored higher; 6 did not differ), outperforming 33 among a total of 47 participants (Appendix Table 1-18). At grade 8, the U.S. average science score was also among the top 14 education systems (7 scored higher; 6 did not differ), outperforming 23 among a total of 37 participants (Appendix Table 1-19). As with mathematics, the 5 Asian education systems of Singapore, South Korea, Hong Kong, Taiwan, and Japan were among the top scorers on the science assessment at both grade levels (▦ Table 1-9).

TABLE 1-8

Average TIMSS science scores of U.S. students in grades 4 and 8, by selected student and school characteristics: 2015

(Average score)

Characteristic	Grade 4	Grade 8
U.S. total	546	530
Sex		
Male	548	533
Female	544	527
Race or ethnicity		
White	570	557
Black	501	469
Hispanic	518	502
Asian	598	573
Native Hawaiian or Pacific Islander	503	498
American Indian or Alaska Native	530	497
Multiracial	571	536
Percentage of public school students eligible for free or reduced-price lunch		
Less than 10%	603	579
10% to 24.9%	584	563
25% to 49.9%	565	544
50% to 74.9%	541	519
75% or more	502	489
Percentiles		
10th percentile	439	421
25th percentile	495	475
75th percentile	602	588
90th percentile	644	631

TIMSS = Trends in International Mathematics and Science Study.

Note(s)

Black includes African American, and Hispanic includes Latino. Racial categories exclude Hispanic origin. Data on free or reduced-price lunch are for public schools only.

Source(s)

Provasnik S, Malley L, Stephens M, Landeros K, Perkins R, Tang JH, *Highlights From TIMSS and TIMSS Advanced 2015: Mathematics and Science Achievement of U.S. Students in Grades 4 and 8 and in Advanced Courses at the End of High School in an International Context*, NCES 2017-002 (2016); U.S. Department of Education, National Center for Education Statistics, TIMSS data tables, Table 41. Average science scores of U.S. 4th-grade students, by selected characteristics: 2015, https://nces.ed.gov/timss/timss2015/timss2015_table41.asp, accessed 15 September 2017, and Table 42. Average science scores of U.S. 8th-grade students, by selected characteristics: 2015, https://nces.ed.gov/timss/timss2015/timss2015_table42.asp, accessed 15 September 2017.

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TABLE 1-9

Average TIMSS science scores of students in grades 4 and 8, by education system: 2015

(Average score)

Comparison with U.S. score	Education system	Grade 4	Education system	Grade 8
Score higher than that of the United States	Singapore[a]	590	Singapore[a]	597
	South Korea	589	Japan	571
	Japan	569	Taiwan (China)	569
	Russia	567	South Korea	556
	Hong Kong (China)[a]	557	Slovenia	551
	Taiwan (China)	555	Hong Kong (China)	546
	Finland	554	Russia	544
Score not statistically different from that of the United States	Kazakhstan	550	England (UK)	537
	Poland	547	Kazakhstan	533
	United States[a]	546	Ireland	530
	Slovenia	543	United States[a]	530
	Hungary	542	Hungary	527
	Sweden[a]	540	Canada[a]	526
	Bulgaria	536	Sweden	522
Score lower than that of the United States (selected countries)	Norway (grade 5)[a]	538	Lithuania[a]	519
	England (UK)	536	New Zealand[a]	513
	Czech Republic	534	Australia	512
	Croatia	533	Norway (grade 9)[a]	509
	Ireland	529	Israel[a]	507
	Germany	528	Italy[a]	499
	Lithuania[a]	528	Turkey	493

Comparison with U.S. score	Education system	Grade 4	Education system	Grade 8
	Denmark[a]	527	Malta	481
	Canada[a]	525	United Arab Emirates	477
	Serbia[a]	525	Malaysia	471

TIMSS = Trends in International Mathematics and Science Study; UK = United Kingdom.

[a] See Appendix Table 1-18 and Appendix Table 1-19 for details about TIMSS administration in these education systems.

Note(s)

Education systems are ordered by the 2015 average score. The countries shown in the Score lower than that of the United States section are the 10 with the highest average scores below the United States.

Source(s)

Provasnik S, Malley L, Stephens M, Landeros K, Perkins R, Tang JH, *Highlights from TIMSS and TIMSS Advanced 2015: Mathematics and Science Achievement of U.S. Students in Grades 4 and 8 and in Advanced Courses at the End of High School in an International Context*, NCES 2017-002 (2016).

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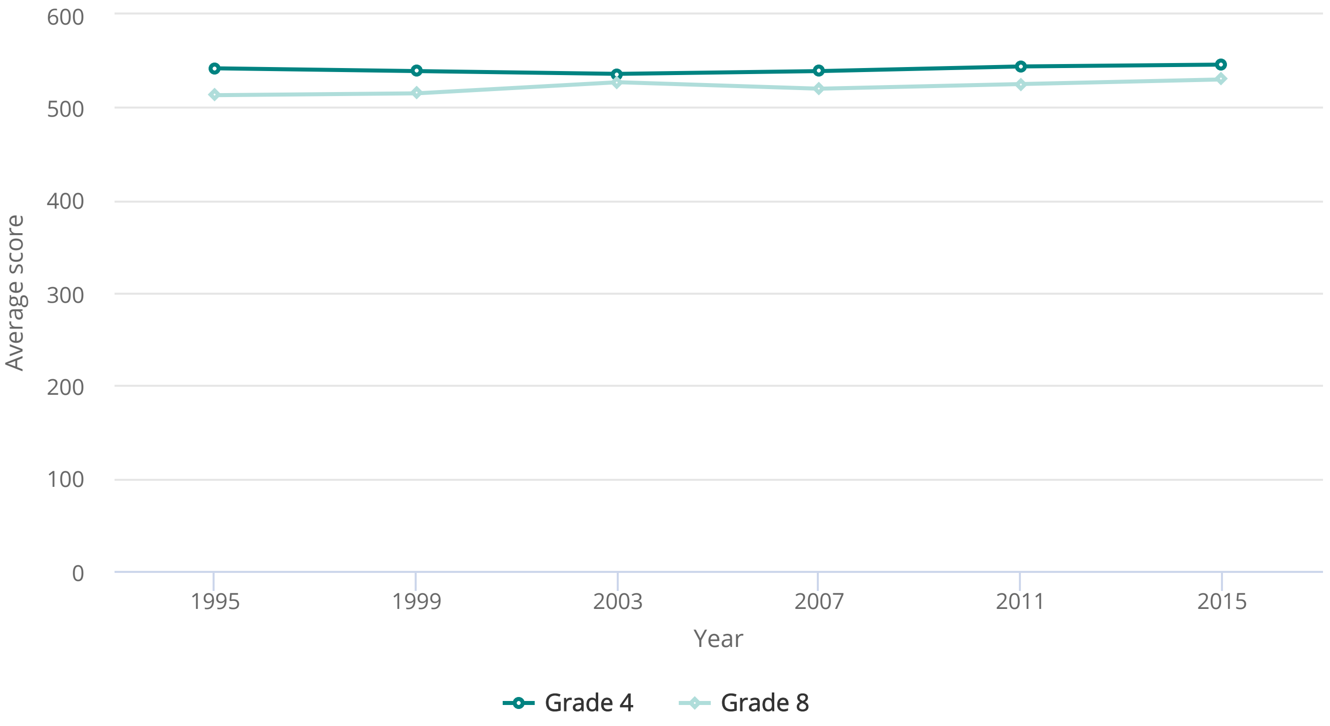
Performance trends. In contrast to the mathematics trends, which showed significant improvement in both grades, the average scores of U.S. students on the TIMSS science assessment remained flat since 1995 for fourth graders but improved 17 points for eighth graders (Figure 1-4). U.S. fourth and eighth graders have not improved their international position in science achievement since 1995. Among the 17 education systems that participated in the 1995 and 2015 grade 4 TIMSS science assessments, the United States slipped in rank, from 3rd in 1995 to 5th in 2015; at grade 8, the position of the United States did not move between 1995 and 2015 (Provasnik et al. 2016).

FIGURE 1-4

Average TIMSS science scores of U.S. students in grades 4 and 8: 1995–2015



TIMSS = Trends in International Mathematics and Science Study.

Note(s)

TIMSS science assessment scores range from 0 to 1,000 for grades 4 and 8. U.S. fourth graders did not participate in TIMSS in 1999; score is interpolated. Average science scores of students in grade 4 and grade 8 cannot be compared directly because the test items differ across grade levels to reflect the nature, difficulty, and emphasis of the subject matter taught in school at each grade.

Source(s)

Provasnik S, Malley L, Stephens M, Landeros K, Perkins R, Tang JH, *Highlights From TIMSS and TIMSS Advanced 2015: Mathematics and Science Achievement of U.S. Students in Grades 4 and 8 and in Advanced Courses at the End of High School in an International Context*, NCES 2017-002 (2016).

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Demographic differences. As with mathematics, U.S. students' science scores differed according to the percentage of students eligible for free or reduced-price lunch at participants' schools, with students at schools with less than 10% of eligible students scoring approximately 100 points higher than students at schools with 75% or more eligible students at fourth (603 versus 502) and eighth (579 versus 489) grade (Table 1-8). At grade 4 and grade 8, there were no significant differences in average scores between male and female students. The average scores for Asian (598) and white (570) students in grade 4 were significantly higher than the scores for Hispanic (518) and black (501) students. A similar pattern was seen for students in grade 8.

U.S. Performance in TIMSS Advanced Mathematics and Physics at the End of High School

Only U.S. performance on TIMSS Advanced is reported here because countries varied in their rates of participation in the exam and in the characteristics of students taking the assessment, making it difficult to accurately rank education systems in order of performance. IEA calculates a coverage index for the advanced mathematics and physics exams for education systems participating in the exam. The coverage index is the percentage of all people in an age cohort who are students in their final year of secondary school who have taken or are taking advanced mathematics or physics courses. The corresponding age cohort is determined for education systems individually. In the United States, 18-year-olds are considered to be the corresponding age cohort. The U.S. coverage index was 11.4 for advanced mathematics and 4.8 for physics. The coverage index for advanced mathematics for other education systems ranged from 3.9 for Lebanon to 34.4 for Slovenia. The coverage index for physics ranged from 3.9 for Lebanon to 21.5 for France.[10]

Performance trends. In 2015, the U.S. average scores were 485 in advanced mathematics and 437 in physics (▦ Table 1-10). These scores are not significantly different from the scores reported for both exams in 1995 (Provasnik et al. 2016). The effective score range for the mathematics exam was about 250 points, with 80% of scores (from the 10th to the 90th percentiles) falling between 352 and 608. The score range for physics was larger, at more than 300 points, with 80% of scores falling between 283 and 589.

Demographic differences. U.S. students' average scores on the advanced mathematics and physics assessments differed according to the percentage of students eligible for free or reduced-price lunch at participants' schools (▦ Table 1-10). In advanced mathematics, students at schools with less than 10% of students eligible scored more than 100 points higher than students at schools with 75% or more eligible (534 versus 425). In physics, the difference in average scores was nearly 150 points (506 versus 363). The average scores for U.S. male students on both TIMSS Advanced assessments were considerably higher than those for female students. Male students outperformed female students by 30 points on the TIMSS Advanced mathematics assessment and by 46 points on the physics assessment. The proportion of male and female students taking the advanced mathematics assessment was close to even, but the physics exam was skewed toward male students, with U.S. male students comprising 61% of exam takers (Provasnik et al. 2016). As with the fourth and eighth grade students in mathematics and science, the average scores on the advanced mathematics assessment were higher for white (495) and Asian (506) students than for Hispanic (440) and black (400) students. A similar pattern in average scores was seen among white, black, and Hispanic students on the TIMSS Advanced physics assessment.

TABLE 1-10

Average advanced mathematics and physics scores of U.S. TIMSS Advanced students, by selected student and school characteristics: 2015

(Average score)

Characteristic	Advanced mathematics	Physics
U.S. total	485	437
Sex		
Male	500	455
Female	470	409
Race or ethnicity		
White	495	463
Black	400	334
Hispanic	440	390
Asian	506	433
Multiracial	525	470
Percentage of public school students eligible for free or reduced-price lunch		
Less than 10%	534	506
10% to 24.9%	515	482
25% to 49.9%	485	414
50% to 74.9%	454	426
75% or more	425	363
Percentiles		
10th percentile	352	283
25th percentile	419	357
75th percentile	554	522
90th percentile	608	589

TIMSS = Trends in International Mathematics and Science Study.

Note(s)

Black includes African American, and Hispanic includes Latino. Racial categories exclude Hispanic origin. Data on free or reduced-price lunch are for public schools only.

Source(s)

Provasnik S, Malley L, Stephens M, Landeros K, Perkins R, Tang JH, *Highlights from TIMSS and TIMSS Advanced 2015: Mathematics and Science Achievement of U.S. Students in Grades 4 and 8 and in Advanced Courses at the End of High School in an International Context*, NCES 2017-002 (2016); U.S. Department of Education, National Center for Education Statistics, TIMSS data tables, Table 52. Average advanced mathematics scores of U.S. TIMSS Advanced students, by selected characteristics: 2015, https://nces.ed.gov/timss/timss2015/timss2015_table52.asp, accessed 15 September 2017, and Table 61. Average physics scores of U.S. TIMSS Advanced students, by selected characteristics: 2015, https://nces.ed.gov/timss/timss2015/timss2015_table61.asp, accessed 15 September 2017.

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The Program for International Student Assessment

PISA assessments measure the performance of 15-year-old students in science and mathematics literacy every 3 years. Coordinated by the Organisation for Economic Co-operation and Development (OECD), PISA was first implemented in 2000 in 32 countries and has since grown to 73 education systems in 2015.[11] Participants in PISA include countries and cities, so rankings should be assessed within that context. The United States has participated in every cycle of PISA since its inception in 2000. PISA's goal is to assess students' preparation for the challenges of life as young adults. The study assesses the application of knowledge in science, reading, and mathematics literacy to problems within a real-life context. Unlike TIMSS, PISA does not focus explicitly on school-based curricula and uses the term *literacy* in each subject area to indicate its broad focus on the application of knowledge and skills learned in and outside of school. For example, when assessing science, PISA examines how well 15-year-old students can understand, use, and reflect on science for various real-life problems and settings that they may encounter in and out of school (see sidebar Sample Items from the Program for International Student Assessment Mathematics and Science Assessments).

SIDEBAR

Sample Items from the Program for International Student Assessment Mathematics and Science Assessments

Sample Items from the 2012 Mathematics Assessment

Sample 1

Peter's bicycle has a wheel circumference of 96 cm (or 0.96 m). It is a three-speed bicycle with a low, a middle, and a high gear. The gear ratios of Peter's bicycle are:

Low	*3:1*	*Middle*	*6:5*	*High*	*1:2*

How many pedal turns would Peter take to travel 960 m in middle gear? Show your work.

NOTE: A gear ratio of 3:1 means 3 complete pedal turns yields 1 complete wheel turn.

(Correct answer: 1,200 pedal turns, with a fully correct method.)

Sample 2

One advantage of using a kite sail is that it flies at a height of 150 m. There, the wind speed is approximately 25% higher than down on the deck of the ship.

At what approximate speed does the wind blow into a kite sail when a wind speed of 24 km/h is measured on the deck of the ship?

a. 6 km/h

b. 18 km/h

c. 25 km/h

d. 30 km/h

e. 49 km/h

(Correct answer: D)

Sample Items from the 2015 Science Assessment

Sample 1

Meteoroids and Craters

Rocks in space that enter Earth's atmosphere are called meteoroids. Meteoroids heat up and glow as they fall through Earth's atmosphere. Most meteoroids burn up before they hit Earth's surface. When a meteoroid hits Earth, it can make a hole called a crater.

As a meteoroid approaches Earth and its atmosphere, it speeds up. Why does this happen?

a. The meteoroid is pulled in by the rotation of Earth.

b. The meteoroid is pushed by the light of the Sun.

c. The meteoroid is attracted to the mass of Earth.

d. The meteoroid is repelled by the vacuum of space.

(Correct answer: C)

Sample 2

What is the effect of a planet's atmosphere on the number of craters on a planet's surface?

*The thicker a planet's atmosphere is, the (**1. More or Fewer**) craters its surface will have because (**2. More or Fewer**) meteoroids will burn up in the atmosphere.*

(Correct answer: 1. Fewer; 2. More)

Additional sample questions are available at https://nces.ed.gov/surveys/pisa/pdf/items_math2012.pdf and https://www.oecd.org/pisa/test/PISA2015-Released-FT-Cognitive-Items.pdf.

International Comparison of Mathematics Literacy among U.S. 15-Year-Olds

U.S. students' average PISA mathematics score of 470 in 2015 was lower than the OECD average score of 490, on a scale of 0–1,000 (▦ Table 1-11). The effective score range for U.S. students was 230 points, with 80% of students scoring between 355 and 585. The U.S. average score was lower than that of 36 other education systems and was not significantly different from 5 (Appendix Table 1-20). The top 5 performers were all located in Asia (Singapore, Hong Kong, Macau, Taiwan, and Japan), with average scores surpassing the U.S. score by at least 62 points (▦ Table 1-12). The U.S. students' average mathematics score was also lower than those of several developing countries, including Vietnam (495), Russia (494), and Lithuania (478).[12]

TABLE 1-11

Average scores of U.S. 15-year-old students on the PISA mathematics and science literacy scales, by selected student characteristics: 2015

(Average score)

Student characteristic	Mathematics	Science
OECD average	490	493
All U.S. students	470	496
Sex		
Male	474	500
Female	465	493
Race or ethnicity		
White	499	531
Black	419	433
Hispanic	446	470
Asian or Pacific Islander	498	525
More than one race	475	503
Socioeconomic status		
Bottom quarter	431	457
Second quarter	453	478
Third quarter	480	508
Top quarter	517	546
Percentiles		
10th percentile	355	368
25th percentile	408	425
75th percentile	532	567
90th percentile	585	626

OECD = Organisation for Economic Co-operation and Development; PISA = Program for International Student Assessment.

Note(s)

Reporting standards were not met for American Indian or Alaska Native and Native Hawaiian or Other Pacific Islander. Black includes African American, and Hispanic includes Latino. Students who identified themselves as being of Hispanic origin were classified as Hispanic, regardless of their race. Although data for some races or ethnicities were not shown separately because the reporting standards were not met, they are included in the U.S. totals. The PISA index of economic, social, and cultural status was created using student reports on parental occupation, the highest level of parental education, and an index of home possessions related to family wealth, home educational resources, and possessions related to “classical” culture in the family home. The home possessions relating to classical culture in the family home included possessions such as works of classical literature, books of poetry, and works of art (e.g., paintings). The OECD average is the average of the national averages of the OECD member countries, with each country weighted equally.

Source(s)

Kastberg D, Chan JY, Murray G, *Performance of U.S. 15-Year-Old Students in Science, Reading, and Mathematics Literacy in an International Context: First Look at PISA 2015,* NCES 2017-048 (2016).

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TABLE 1-12

Average mathematics literacy assessment scores for 15-year-olds participating in PISA, by education system: 2015

(Average score)

Education system	Score	OECD member
Score higher than U.S. score of 470		
Singapore	564	N
Hong Kong (China)	548	N
Macau (China)	544	N
Taiwan (China)	542	N
Japan	532	Y
Beijing, Shanghai, Jiangsu, and Guangdong (China)	531	N
South Korea	524	Y
Switzerland	521	Y
Estonia	520	Y
Canada	516	Y
Netherlands	512	Y
Denmark	511	Y
Finland	511	Y
Slovenia	510	Y
Belgium	507	Y
Germany	506	Y
Poland	504	Y
Ireland	504	Y
Norway	502	Y
Austria	497	Y
New Zealand	495	Y
Vietnam	495	N
Russia	494	N

Education system	Score	OECD member
Sweden	494	Y
Australia	494	Y
France	493	Y
United Kingdom	492	Y
Czech Republic	492	Y
Portugal	492	Y
OECD average	490	-
Italy	490	Y
Iceland	488	Y
Spain	486	Y
Luxembourg	486	Y
Latvia	482	Y
Malta	479	N
Lithuania	478	N
Score not statistically different from U.S. score of 470		
Hungary	477	Y
Slovakia	475	Y
Israel	470	Y
United States	470	Y
Croatia	464	N
Buenos Aires (Argentina)	456	N
Score lower than U.S. score of 470 (selected education systems)		
Greece	454	Y
Romania	444	N
Bulgaria	441	N
Cyprus	437	N
United Arab Emirates	427	N

Education system	Score	OECD member
Chile	423	Y
Turkey	420	Y
Moldova	420	N
Uruguay	418	N
Montenegro	418	N

N = no; Y = yes.

OECD = Organisation for Economic Co-operation and Development; PISA = Program for International Student Assessment.

Note(s)

Education systems are ordered by 2015 average score. The OECD average is the average of the national averages of the OECD member countries, with each country weighted equally. Scores are reported on a scale from 0 to 1,000. All average scores reported as higher or lower than the U.S. average score are different at the .05 level of statistical significance. Although Argentina, Malaysia, and Kazakhstan participated in PISA 2015, technical problems with their samples prevent results from being discussed in this report. The countries shown in the Score lower than U.S. score section are the 10 with the highest average scores below the United States.

Source(s)

Kastberg D, Chan JY, Murray G, *Performance of U.S. 15-Year-Old Students in Science, Reading, and Mathematics Literacy in an International Context: First Look at PISA 2015,* NCES 2017-048 (2016). See Appendix Table 1-20.

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International Comparison of Science Literacy among U.S. 15-Year-Olds

The average PISA science literacy score for U.S. students in 2015 was 496, which was not significantly different from the OECD average of 493, on a scale of 0 to 1,000 (▦ Table 1-11). The effective score range for U.S. students was 258 points, with 80% of students scoring between 368 and 626. The U.S. average score was lower than that of 18 other education systems and not significantly different from 12. The top 5 performers on the science exam were Singapore, Japan, Estonia, Taiwan, and Finland, and their average scores surpassed those of the United States by at least 35 points (▦ Table 1-13). Unlike mathematics scores, the U.S. students' average science score was higher than those of all developing countries participating in PISA in 2015 (Appendix Table 1-21).

TABLE 1-13

Average science literacy assessment scores for 15-year-old students participating in PISA, by education system: 2015

(Average score)

Education system	Score	OECD member
Score higher than U.S. score of 496		
Singapore	556	N
Japan	538	Y
Estonia	534	Y
Taiwan (China)	532	N
Finland	531	Y
Macau (China)	529	N
Canada	528	Y
Vietnam	525	N
Hong Kong (China)	523	N
Beijing, Shanghai, Jiangsu, and Guangdong (China)	518	N
South Korea	516	Y
New Zealand	513	Y
Slovenia	513	Y
Australia	510	Y
United Kingdom	509	Y
Germany	509	Y
Netherlands	509	Y
Switzerland	506	Y
Score not statistically different from U.S. score of 496		
Ireland	503	Y
Belgium	502	Y
Denmark	502	Y
Poland	501	Y

Education system	Score	OECD member
Portugal	501	Y
Norway	498	Y
United States	496	Y
Austria	495	Y
France	495	Y
OECD average	493	-
Sweden	493	Y
Czech Republic	493	Y
Spain	493	Y
Latvia	490	Y
Score lower than U.S. score of 496 (selected education systems)		
Russia	487	N
Luxembourg	483	Y
Italy	481	Y
Hungary	477	Y
Lithuania	475	N
Croatia	475	N
Buenos Aires (Argentina)	475	N
Iceland	473	Y
Israel	467	Y
Malta	465	N

N = no; Y = yes.

OECD = Organisation for Economic Co-operation and Development; PISA = Program for International Student Assessment.

Note(s)

Education systems are ordered by 2015 average score. The OECD average is the average of the national averages of the OECD member countries, with each country weighted equally. Scores are reported on a scale from 0 to 1,000. All average scores reported as higher or lower than the U.S. average score are different at the .05 level of statistical significance. Although Argentina, Malaysia, and Kazakhstan participated in PISA 2015, technical problems with their samples prevent results from being discussed in this report. The countries shown in the Score lower than U.S. score section are the 10 with the highest average scores below that of the United States.

Source(s)

Kastberg D, Chan JY, Murray G, *Performance of U.S. 15-Year-Old Students in Science, Reading, and Mathematics Literacy in an International Context: First Look at PISA 2015,* NCES 2017-048 (2016). See Appendix Table 1-21.

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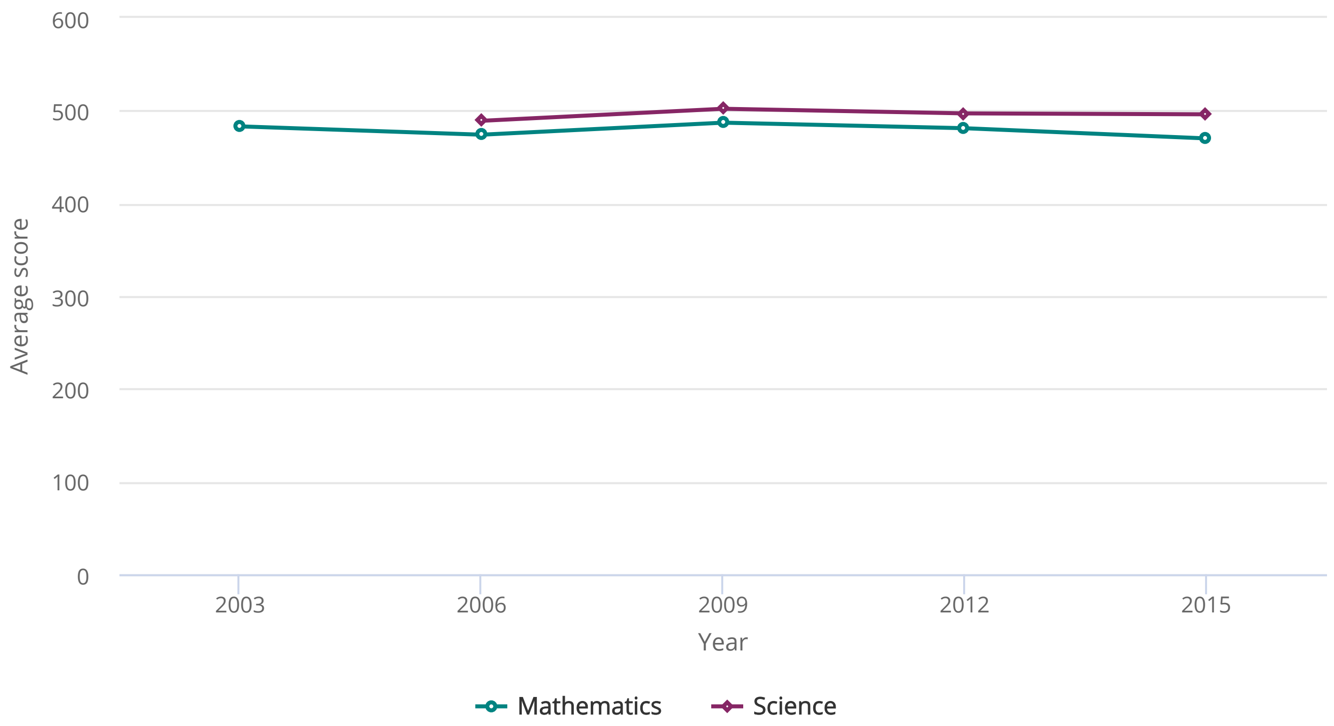
Trends in Mathematics and Science Knowledge among 15-Year-Old Students in the United States: Results from PISA

Figure 1-5 shows the average mathematics and science literacy scores for 15-year-old students in the United States between 2003 and 2015.[13] Scores decreased for mathematics since 2009 but stayed even for science. The U.S. average score in mathematics literacy in 2015 was 17 points lower than the average score in 2009 and 11 points lower than the average in 2012, but it was not significantly different from scores in 2003 and 2006. The U.S. average score in science in 2015 was not significantly different from the average scores observed in 2006, 2009, and 2012.

FIGURE 1-5

Average mathematics and science literacy assessment scores of 15-year-old students in the United States: 2003–15



Note(s)

The mathematics and science literacy assessment scores range from 0 to 1,000. Science data for 2003 are not available; science literacy assessment was not administered that year.

Source(s)

Kastberg D, Chan JY, Murray G, *Performance of U.S. 15-Year-Old Students in Science, Reading, and Mathematics Literacy in an International Context: First Look at PISA 2015,* NCES 2017-048 (2016).

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U.S. Performance on PISA, by Selected Student Characteristics

Average scores for students in the United States varied by SES, sex, and race or ethnicity on the mathematics and science PISA assessments (Table 1-11). The gap in the average scores between students in the highest and lowest socioeconomic quartiles was nearly 90 points on the mathematics assessment (517 versus 431) and the science assessment (546 versus 457). Average scores were also higher for male students than for female students on both assessments, with a gap of 9 points in favor of male students on the mathematics assessment and 7 points on science. Average mathematics scores for white (499) and Asian or Pacific Islander (498) students were higher than those of Hispanic (446) and black (419) students. Similar gaps by race or ethnicity were seen in science performance.

[1] Grade 12 mathematics data are presented from 2005 only because the grade 12 mathematics framework was substantially revised in 2005, making prior assessment results not comparable with those in or after 2005.

[2] Science data are presented beginning in 2009 only because the science framework was substantially revised in 2009, making prior assessment results not comparable with those in or after 2009.

[3] The NAGB, as directed by NAEP legislation, has been developing achievement levels for NAEP since 1990. A broadly representative panel of teachers, education specialists, and the public help define and review achievement levels. As provided by law, the achievement levels are to be used on a trial basis and should be interpreted and used with caution. More information about NAEP achievement levels is available at https://nces.ed.gov/nationsreportcard/achievement.aspx.

[4] TIMSS required participating countries and other education systems to draw probability samples of students who were nearing the end of their fourth or eighth year of formal schooling. In the United States, one sample was drawn to represent the nation at grade 4 and another at grade 8. The U.S. national sample included public and private schools, randomly selected and weighted to be representative of the nation at grade 4 and at grade 8.

[5] TIMSS Advanced required participating countries and other education systems to draw probability samples of students in their final year of secondary school who were taking or had taken courses in advanced mathematics or physics. In the United States, two samples of twelfth graders were drawn to represent the nation—one for advanced mathematics and one for physics. The courses that defined the target populations had to cover most, if not all, of the advanced mathematics and physics topics that were outlined in the assessment frameworks. In the United States, this was defined as a calculus course for eligibility for the advanced mathematics population and an advanced physics course, such as AP physics, for the physics population. The U.S. national samples included public and private schools, randomly selected and weighted to be representative of the nation's advanced mathematics and physics coursetakers at the end of high school.

[6] Non-national entities that are not IEA member countries (e.g., Abu Dhabi, Buenos Aires) may participate in TIMSS to assess their comparative international standing. These entities are designated as “benchmarking participants.”

[7] Results presented here are for 48 education systems at grade 4 and 37 at grade 8 because Armenia is excluded. Although Armenia did participate in TIMSS 2015 at grades 4 and 8, the country's results are not reported by TIMSS because the data are not comparable for trend analysis.

[8] The scores are reported on a scale from 0 to 1,000, with the TIMSS scale average set at 500 and the standard deviation set at 100.

[9] The TIMSS results presented in this report exclude individual U.S. states, Canadian provinces, Abu Dhabi, Buenos Aires, and Dubai. These states and provinces participated in 2015 TIMSS as “benchmarking participants” to assess the comparative international standing of their students' achievement and to view their curriculum and instruction in an international context.

[10] For additional details, see the Technical Notes available at https://nces.ed.gov/timss/timss15technotes.asp.

[11] Of the 73 education systems that participated in PISA 2015, results for three of these—Argentina, Kazakhstan, and Malaysia—are not included due to technical issues with their samples that prevent results from being discussed in this report.

[12] Developing countries in this report are any countries that do not appear on the International Monetary Fund list of “advanced economies.”

[13] The PISA mathematics assessment was also conducted in 2000 but, because the framework for the mathematics assessment was revised in 2003, it is not appropriate to compare results from the 2000 assessment with subsequent PISA mathematics assessments. Similarly, the framework for the PISA science assessment was changed in 2000 and in 2003, preventing comparisons of results in 2000 or 2003 with science literacy scores from subsequent years.

High School Coursetaking in Mathematics and Science

To understand students' achievement in mathematics or science, it helps to understand what courses they have taken. In addition, STEM coursetaking in high school is predictive of earning a STEM degree in postsecondary education, with students who take more advanced mathematics and science in high school more likely to complete college with a STEM degree (Tyson et al. 2007; Wang 2013). This section examines high school students' participation in mathematics and science courses using data from HSLS:09, the College Board's AP program, and data collected by the Department of Education's Office for Civil Rights.

HSLS:09 is a longitudinal study of a nationally representative sample of approximately 20,000 students who were first surveyed in fall 2009 as ninth graders and were surveyed again in 2012, when most were spring-term eleventh graders. The HSLS:09 sample includes students from public and private schools, so it is representative of the overall in-school population. It does not include home-schooled students, who make up about 3% of the student population in the United States (Redford, Battle, and Bielick 2017). Transcript data were collected for HSLS:09 students in summer 2013, when most would have completed high school (Dalton, Ingels, and Fritch 2016). Compared with students' self-reports of coursetaking, transcript data provide a more accurate account of mathematics and science coursetaking for all students in the study for whom transcripts were collected. Transcript data are used in this section to examine the mathematics and science courses taken by students who had completed high school by summer 2013.

Given the ongoing emphasis on readiness for college and career at the completion of high school (Achieve Inc. 2016), this section focuses specifically on mathematics and science coursetaking among high school completers (i.e., students who graduated from high school with a regular diploma or an alternative credential such as a General Educational Development [GED] certificate). It is recommended that high school graduates interested in attending a public university complete a minimum of 3 years of mathematics, including algebra 2, and 3 years of science, including biology and either chemistry or physics (Bromberg and Theokas 2016).

Highest Mathematics Courses Taken by High School Completers

Among ninth graders who began high school in 2009 and completed high school in 2013, the majority (89%) completed algebra 2 or higher (▦ Table 1-14). More specifically, approximately one-quarter of students stopped with algebra 2 as their highest mathematics course, another quarter stopped with trigonometry or other advanced mathematics, 22% advanced to pre-calculus, and 19% finished with calculus or higher.

Socioeconomic status. Students in the highest SES quintile were more likely to take advanced mathematics courses than their peers in the middle and lowest SES quintiles (▦ Table 1-14). For example, the percentage of students in the highest SES quintile taking calculus or higher was four times higher than the percentage of students in the lowest SES quintile (37% versus 9%) and two times higher than the percentage of students in the middle SES quintiles (37% versus 16%).

TABLE 1-14

Highest-level mathematics course enrollment of high school completers, by student and family characteristics: 2013

(Percent)

Student and family characteristic	Algebra 1 or lower	Geometry	Algebra 2	Trigonometry or other	Pre-calculus	Calculus or higher
All students	2.9	7.8	24.4	23.8	21.8	19.3
Sex						
Male	3.7	9.1	23.7	23.7	20.4	19.5
Female	2.2	6.5	25.1	24.0	23.2	19.2
Race or ethnicity						
White	3.2	6.6	22.2	22.2	23.9	22.0
Black	2.3	4.9	28.8	34.6	20.4	9.0
Hispanic[a]	3.0	13.2	26.8	23.5	18.9	14.6
Asian	0.7	2.4	10.3	13.6	22.7	50.3
Other[b]	2.8	10.7	43.8	15.7	12.6	14.3
Two or more races	3.1	8.1	30.8	25.1	17.8	15.1
SES[c]						
Lowest fifth	4.9	12.0	31.0	26.5	16.6	9.0
Middle three-fifths	3.2	8.2	26.5	25.1	20.9	16.2
Highest fifth	0.5	3.3	11.6	18.9	28.9	36.7

SES = socioeconomic status.

[a] Hispanic may be any race. Asian, black, white, and other races refer to individuals who are not of Hispanic origin.

[b] Other includes Alaska Native, American Indian, Native Hawaiian, Pacific Islander, and those having origins in a race not listed.

[c] SES is a composite variable derived from parental education level, parental occupation, and family income. The quintile measure divides the SES distribution into five equal quintile groups. Quintile 1 corresponds to the lowest one-fifth of the population, and quintile 5 corresponds to the highest. For this report, the middle three quintiles are combined into one category.

Note(s)

Trigonometry or other includes trigonometry, probability and statistics, and other advanced mathematics. Calculus or higher includes calculus, Advanced Placement or International Baccalaureate (AP/IB) calculus, and other AP/IB mathematics. Percentages may not add to total because of rounding.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2016) of High School Longitudinal Study of 2009 (HSLS:09), National Center for Education Statistics. See Appendix Table 1-22.

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Race or ethnicity. Asian students took advanced mathematics courses at a significantly higher rate than any other racial or ethnic group, with 50% taking calculus or higher, compared with 22% for white students, 15% for Hispanic students, and 9% for black students. Although 13% of Hispanic students stopped with geometry 1 as their highest mathematics course, just 2%–7% of white, black, and Asian students did so.

Sex. Approximately the same percentage of male and female students stopped with algebra 2, trigonometry, or calculus or higher as their highest mathematics course.

Socioeconomic status and sex by race or ethnicity. Virtually no sex differences were detected in mathematics coursetaking within each racial or ethnic group (Appendix Table 1-22). However, mathematics coursetaking gaps by SES persisted even after race or ethnicity was considered (▦ Table 1-15). In all racial or ethnic groups, students in the highest SES quintile took advanced mathematics such as calculus at higher rates than low-SES students. Among Asian students, for example, 63% of those in the highest SES quintile took calculus compared with 30% of low-SES students. For white students, when comparing calculus coursetaking, it was 38% in the highest SES quintile versus 8% in the lowest SES quintile; for black students, it was 22% versus 3%; and for Hispanic students, it was 25% versus 12%. This pattern was reversed for lower-level mathematics coursetaking, with low-SES students in most racial or ethnic groups more likely than their high-SES peers to stop taking mathematics at the lower course levels. For example, 37% of low-SES white students took algebra 2 as their highest mathematics course, compared with 11% of high-SES white students.

TABLE 1-15

Highest-level mathematics course enrollment of high school completers, by socioeconomic status within race or ethnicity: 2013

(Percent)

Student and family characteristic	Algebra 1 or lower	Geometry	Algebra 2	Trigonometry or other	Pre-calculus	Calculus or higher
All students	2.9	7.8	24.4	23.8	21.8	19.3
White						
Lowest fifth SES	8.0	8.6	37.2	23.6	14.8	7.8
Middle three-fifths SES	3.6	8.0	25.4	23.7	22.3	17.1
Highest fifth SES	0.5	2.6	10.5	18.6	30.2	37.6
Black						
Lowest fifth SES	3.5	4.1	32.4	38.5	18.5	3.1
Middle three-fifths SES	2.3	5.4	27.3	34.7	21.0	9.4
Highest fifth SES	0.5	4.8	15.2	33.4	23.9	22.2
Hispanic[a]						
Lowest fifth SES	3.2	18.6	23.7	25.6	17.0	11.9
Middle three-fifths SES	3.1	11.2	29.0	23.8	18.5	14.5
Highest fifth SES	0.6	7.3	18.6	16.6	31.9	25.1
Asian						
Lowest fifth SES	0.0	8.0	19.2	16.9	25.8	30.0
Middle three-fifths SES	1.4	1.7	12.4	18.5	20.9	45.1
Highest fifth SES	0.0	1.9	4.8	6.3	24.3	62.7

SES = socioeconomic status.

[a] Hispanic may be any race. Asian, black, and white refer to individuals who are not of Hispanic origin.

Note(s)

Trigonometry or other includes trigonometry, probability and statistics, and other advanced mathematics. Calculus or higher includes calculus, Advanced Placement or International Baccalaureate (AP/IB) calculus, and other AP/IB mathematics. SES is a composite variable derived from parental education level, parental occupation, and family income. The quintile measure divides the SES distribution into five equal quintile groups. Quintile 1 corresponds to the lowest one-fifth of the population, and quintile 5 corresponds to the highest. For this report, the middle three quintiles are combined into one category.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2016) of High School Longitudinal Study of 2009 (HSLS:09), National Center for Education Statistics. See Appendix Table 1-23.

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Other characteristics. The highest level of mathematics coursetaking was also positively related to parents' highest education and students' mathematics achievement, mathematics coursetaking, and educational expectations in ninth grade (Appendix Table 1-23). In addition, students who attended private school took advanced courses at higher rates than students who attended public schools. For example, 33% of students at private schools took calculus or higher, compared with 18% of students at public schools.

Science Coursetaking by High School Completers

All ninth graders who began high school in 2009 and completed in 2013 took at least one science course, with 79% taking at least one general science course (but no advanced science) and 21% taking at least one advanced course (▦Table 1-16). Virtually all students (98%) took biology, 76% took chemistry, and fewer (41%) took physics.

Socioeconomic status. Although all students took at least one science course, students in the highest SES quintile were more than three times as likely to take at least one advanced science course compared with their peers in the lowest SES quintile (38% versus 11%). In addition, students in the highest SES quintile were more likely to take chemistry and physics courses than students in the lowest SES quintile.

Race or ethnicity. Among all racial or ethnic groups, Asian students were the most likely to take advanced science courses, by a large margin. For example, 25% of Asian students took advanced chemistry, compared with 9% of white students, 3% of black students, and 5% of Hispanic students. The percentage of students who took general physics was not significantly different among white, black, and Hispanic students.

Sex. Science coursetaking showed slight differences among male and female students. For example, 78% of female students took chemistry, compared with 73% of male students. The pattern reversed slightly for physics, with 40% of female students taking physics, compared with 43% of male students. In advanced coursetaking, female students were slightly more likely than male students to take advanced biology (13% versus 10%) and slightly less likely to take advanced physics (4% versus 7%).

Socioeconomic status and sex by race or ethnicity. Within each racial or ethnic group, students in the highest SES quintile were more likely to take at least one advanced science course compared with their counterparts in the lowest SES quintile (▦Table 1-17). Thirty-eight percent of high-SES white, 31% of high-SES black, and 31% of high-SES Hispanic students took at least one advanced science course, compared with approximately 10% of their peers in the lowest SES quintile.

Some sex differences in science coursetaking were observed when race or ethnicity was taken into account (Appendix Table 1-24). White female students were more likely than white male students to take chemistry (79% versus 73%), and white male students were more likely than white female students to take physics (45% versus 39%). Black female students were more likely to take at least one advanced science course than their male counterparts (18% versus 9%), specifically advanced biology (12% versus 5%).

Other characteristics. Science coursetaking also varied by parental education level, students' mathematics achievement and coursetaking, and educational expectations (Appendix Table 1-25). For example, students who enrolled in a course above algebra 1 in ninth grade took advanced biology, chemistry, and physics at higher rates, compared with students who enrolled in algebra 1 in ninth grade (19% versus 7% for biology, 14% versus 4% for chemistry, and 11% versus 2% for physics). About 85% of students at public and private schools took general biology, but students at private schools took general chemistry and physics at higher rates than their public school counterparts (81% versus 67% and 54% versus 35%, respectively).

TABLE 1-16

Science course enrollment of high school completers, by student and family characteristics: 2013

(Percent)

Student and family characteristic	General science	AP/IB or advanced science	No biology	General biology	AP/IB or advanced biology	No chemistry	General chemistry	AP/IB or advanced chemistry	No physics	General physics	AP/IB or advanced physics
All students	78.6	21.3	2.5	86.1	11.5	24.4	67.9	7.7	58.5	36.4	5.1
Sex											
Male	80.2	19.7	2.7	87.7	9.7	27.1	65.4	7.5	56.7	36.8	6.6
Female	77.1	22.8	2.2	84.5	13.2	21.9	70.2	7.9	60.3	36.0	3.7
Race or ethnicity											
White	76.6	23.3	2.4	85.3	12.4	23.9	67.3	8.8	58.3	36.3	5.4
Black	85.4	14.4	1.2	89.8	9.0	23.8	72.8	3.4	62.8	34.8	2.4
Hispanic[a]	84.0	15.9	2.9	89.2	7.9	27.1	68.1	4.8	59.6	36.9	3.5
Asian	48.5	51.5	3.8	66.1	30.1	10.1	65.2	24.7	32.9	47.4	19.8
Other[b]	91.5	7.7	2.7	91.2	6.1	33.0	63.2	3.7	74.5	25.1	0.4
Two or more races	81.1	18.9	2.9	86.9	10.3	28.1	65.6	6.4	62.0	33.2	4.7
SES[c]											
Lowest fifth	89.1	10.6	3.3	90.3	6.4	34.1	62.4	3.5	68.1	30.1	1.9
Middle three-fifths	81.2	18.6	2.1	87.5	10.4	25.8	68.0	6.2	60.8	35.2	4.0

Student and family characteristic	General science	AP/IB or advanced science	No biology	General biology	AP/IB or advanced biology	No chemistry	General chemistry	AP/IB or advanced chemistry	No physics	General physics	AP/IB or advanced physics
Highest fifth	62.0	38.0	2.4	78.6	19.0	11.9	72.8	15.4	43.6	45.9	10.5

AP/IB = Advanced Placement/International Baccalaureate; SES = socioeconomic status.

[a] Hispanic may be any race. Asian, black or African American, white, and other races refer to individuals who are not of Hispanic origin.

[b] Other includes Alaska Native, American Indian, Native Hawaiian, Pacific Islander, and those having origins in a race not listed.

[c] SES is a composite variable derived from parental education level, parental occupation, and family income. The quintile measure divides the SES distribution into five equal quintile groups. Quintile 1 corresponds to the lowest one-fifth of the population, and quintile 5 corresponds to the highest. For this report, the middle three quintiles are combined into one category.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2016) of High School Longitudinal Study of 2009 (HSLS:09), National Center for Education Statistics. See Appendix Table 1-24.

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TABLE 1-17

Science course enrollment of high school completers, by socioeconomic status within race or ethnicity: 2013

(Percent)

Student and family characteristic	General science	AP/IB or advanced science	No biology	General biology	AP/IB or advanced biology	No chemistry	General chemistry	AP/IB or advanced chemistry	No physics	General physics	AP/IB or advanced physics
All students	78.6	21.3	2.5	86.1	11.5	24.4	67.9	7.7	58.5	36.4	5.1
White											
Lowest fifth SES	89.7	10.1	2.7	91.9	5.5	40.3	55.4	4.4	72.3	26.7	1.0
Middle three-fifths SES	80.9	18.9	2.4	87.0	10.6	26.8	66.3	6.9	62.7	33.2	4.0
Highest fifth SES	62.3	37.8	2.2	79.2	18.6	11.4	73.8	14.7	44.0	46.2	9.8
Black											
Lowest fifth SES	89.2	10.2	2.3	90.9	6.9	25.0	69.9	5.1	66.6	28.9	4.5
Middle three-fifths SES	85.5	14.5	0.6	90.2	9.2	25.7	71.5	2.8	61.8	37.0	1.3
Highest fifth SES	69.3	30.7	1.9	80.8	17.3	14.9	80.6	4.5	51.5	43.5	5.0
Hispanic[a]											
Lowest fifth SES	89.0	10.7	4.3	88.6	7.2	32.5	65.3	2.2	65.8	33.1	1.1

Student and family characteristic	General science	AP/IB or advanced science	No biology	General biology	AP/IB or advanced biology	No chemistry	General chemistry	AP/IB or advanced chemistry	No physics	General physics	AP/IB or advanced physics
Middle three-fifths SES	83.4	16.6	1.9	90.5	7.7	24.8	70.6	4.7	56.8	39.9	3.4
Highest fifth SES	68.8	30.7	2.2	85.4	12.4	13.0	71.7	15.3	47.4	42.4	10.2
Asian											
Lowest fifth SES	69.3	30.7	5.8	79.5	14.7	18.8	72.0	9.2	50.5	38.2	11.3
Middle three-fifths SES	56.0	44.0	3.3	70.1	26.6	10.6	71.0	18.5	35.8	47.6	16.6
Highest fifth SES	32.3	67.7	4.0	56.5	39.5	7.3	55.7	37.0	23.0	51.5	25.5
Other[b]											
Lowest fifth SES	s	s	s	s	s	s	s	s	s	s	s
Middle three-fifths SES	88.6	10.2	3.7	88.2	8.1	29.6	64.9	5.5	76.0	23.7	0.3
Highest fifth SES	s	s	s	s	s	s	s	s	s	s	s
Two or more races											

Student and family characteristic	General science	AP/IB or advanced science	No biology	General biology	AP/IB or advanced biology	No chemistry	General chemistry	AP/IB or advanced chemistry	No physics	General physics	AP/IB or advanced physics
Lowest fifth SES	93.3	6.7	1.6	95.9	2.5	46.5	50.7	2.8	73.2	26.8	0.0
Middle three-fifths SES	81.8	18.2	2.5	87.2	10.2	27.1	67.4	5.5	63.5	31.9	4.6
Highest fifth SES	70.4	29.6	3.5	82.1	14.4	16.5	71.6	12.0	46.4	44.3	9.3

s = suppressed for reasons of confidentiality and/or reliability.

AP/IB = Advanced Placement/International Baccalaureate; SES = socioeconomic status.

[a] Hispanic may be any race. Asian, black, white, and other races refer to individuals who are not of Hispanic origin.

[b] Other includes Alaska Native, American Indian, Native Hawaiian, Pacific Islander, and those having origins in a race not listed.

Note(s)

SES is a composite variable derived from parental education level, parental occupation, and family income. The quintile measure divides the SES distribution into five equal quintile groups. Quintile 1 corresponds to the lowest one-fifth of the population, and quintile 5 corresponds to the highest. For this report, the middle three quintiles are combined into one category.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2016) of High School Longitudinal Study of 2009 (HSLS:09), National Center for Education Statistics.

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Computer Science and Technology Coursetaking

Computer science and coding skills are increasingly recognized as an asset in today's economy. The Bureau of Labor Statistics projects 23% growth from 2014 to 2024 in the computer systems design and related services industry—from 1,777,700 jobs in 2014 to 2,186,600 jobs in 2024 (U.S. Department of Labor 2015). In light of this projected growth, educators and policymakers, concerned that too few students are exposed to computer science instruction in school, are working to broaden access to computer science courses (Change the Equation 2016; Nager and Atkinson 2016). An analysis of data from NAEP's grade 12 student survey in 2015 showed that just 22% of students reported taking a course in computer programming while in high school (Change the Equation 2016). Several efforts related to computer science education are currently under way and these developments, detailed in the sidebar Focus on Computer Science, herald a new focus on computer science in K–12 education.

SIDEBAR

Focus on Computer Science

Recent years have seen a surge in new developments in computer science education, including a Presidential Memorandum from the Trump administration focused on expanding access to computer science education, the inclusion of computer science in the Every Student Succeeds Act, the launch of a new Advanced Placement computer science course, a growing number of states allowing computer science to count toward high school graduation, and the release of a computer science education framework.

A Presidential Memorandum, signed in September 2017, set a goal of devoting at least $200 million per year in grant funds toward expanding access to high-quality STEM and computer science education.* In conjunction with the Presidential Memorandum, several of the nation's largest technology companies pledged a total of $300 million to support computer science education over a five-year period.[†]

An earlier federal initiative, Computer Science for All, was announced by the Obama administration in early 2016. Although Congress did not approve the specific funding called for in the Computer Science for All initiative, other efforts related to it, such as investments by the National Science Foundation and the Corporation for National and Community Service to support and train computer science teachers, are moving forward.

The Every Student Succeeds Act specifically includes computer science as part of science, technology, engineering, and mathematics education subjects and includes computer science with other core subjects, such as English, reading, science, and mathematics, in its definition of a "well-rounded education."[‡]

The College Board's newest Advanced Placement course, Computer Science Principles, developed with the support of $9 million in funding from NSF, was offered for the first time during the 2016–17 school year. The course, designed to increase the number and diversity of high school students taking computer science, focuses on several topics in addition to programming, including working with data, computational thinking processes, algorithms, understanding the Internet, and cybersecurity.[§]

In 2017, 31 states and the District of Columbia allowed students to count a computer science course toward high school graduation requirements, up from 12 states in 2013.[‖]

The Association for Computing Machinery, Code.org, Computer Science Teachers Association, Cyber Innovation Center, and National Math and Science Initiative collaborated with states, districts, and the computer science education community to develop conceptual guidelines for computer science education. The K–12 Computer Science Framework outlines the essential computer science concepts and practices that students should know by the end of grades 2, 5, 8, and 12.[#]

[*] https://www.whitehouse.gov/the-press-office/2017/09/25/memorandum-secretary-education

[†] https://www.nytimes.com/2017/09/26/technology/computer-science-stem-education.html

[‡] https://www.gpo.gov/fdsys/pkg/BILLS-114s1177enr/pdf/BILLS-114s1177enr.pdf

[§] https://advancesinap.collegeboard.org/stem/computer-science-principles

[‖] https://code.org/action

#https://k12cs.org/

Longitudinal data from HSLS:09, a study that followed a cohort of ninth graders beginning high school in 2009 over 4 years of high school, indicate that 47% of 2013 high school graduates earned credit in computer and information sciences, and 15% earned credit in engineering and technology (Table 1-18; Appendix Table 1-26).[1] The average credits earned were 1.0 credit for computer and information sciences and 1.3 credits for engineering and technology. About two and a half times as many male students (21%) earned engineering and technology credits compared with female students (8%). No significant difference was detected in the percentage of male and female students earning credits for computer and information sciences. It is important to note that computer and information sciences credits reported above included credits earned for introductory courses as well as applied courses focused on learning and using specific software programs. These introductory courses do not fall under the more rigorous definition of computer science as "the study of computers and algorithmic processes, including their principles, design, implementation and impact on society" endorsed by the new K–12 Computer Science Framework (K-12 Computer Science Framework 2016).

TABLE 1-18

Average high school credits earned in technology-related courses and percentage of students earning any credit, for fall 2009 ninth graders, by sex: 2013

(Average number of credits and percentage of students)

Sex	Computer and information sciences		Engineering and technology	
	Average credits	Earned any credit	Average credits	Earned any credit
Total	1.0	47.1	1.3	14.7
Male	1.1	49.0	1.4	21.1
Female	1.0	45.1	1.0	8.3

Source(s)

Dalton B, Ingels SJ, Fritch L, *High School Longitudinal Study of 2009 (HSLS:09) 2013 Update and High School Transcript Study: A First Look at Fall 2009 Ninth-Graders in 2013,* NCES 2015-037rev (2016).

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Data collected as part of a multiyear research effort by Gallup and Google give further insight into the state of computer science education in the United States (Google Inc. and Gallup Inc. 2016). Gallup interviewed nationally representative samples of students, parents, teachers, principals, and superintendents in late 2015 and early 2016. Data from the survey of principals reveal the extent of student access to computer science courses. A total of 57% of principals reported that their school offered at least one computer science course, although, again, these could be applied courses in how to use software programs that do not meet the more rigorous definition of computer science advocated in the new K–12 Computer Science Framework (Table 1-19). Fewer principals reported offering computer science courses with advanced content, ranging from 40% reporting courses that included computer programming to 14% reporting courses that included data analytics or visualization (Google Inc. and Gallup Inc. 2016). Computer science courses were more likely to be offered at larger schools, with 78% of principals at schools with 1,000 or more students reporting offering at least one computer science course, compared with 47% of principals at schools with less than 500 students (Table 1-19). Computer science courses were also more available at high schools (75%) than at middle schools (51%) and elementary schools (39%). When principals at schools that offered no computer science were asked why such courses were not offered, 63% indicated that teachers with the necessary skills were not available, 55% responded that they did not have sufficient funds to train and hire a teacher, and 50% noted the lack of time in their class schedule for subjects other than those with testing requirements (Google Inc. and Gallup Inc. 2016).

TABLE 1-19

Percentage of principals reporting that their schools offer at least one computer science course, by grade level, size, and locale: 2016

(Percent)

Characteristic	At least one computer science course
Total	57
Grade level	
6th and lower	39
7th and 8th	51
9th and higher	75
Size	
Less than 500	47
500–999	51
1,000 or more	78
Locale	
City	44
Suburb	69
Town or rural	57

Source(s)

Google Inc. & Gallup Inc., *Trends in the State of Computer Science in U.S. K–12 Schools* (2016), figure B7, https://goo.gl/j291E0, accessed 16 March 2017.

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Participation and Performance in the Advanced Placement Program

The AP program is one of the largest and most well-known programs offering high school students the opportunity to earn college credits. Other such opportunities include the International Baccalaureate program, which also offers college credits to high school students, and dual enrollment, in which students enroll in college courses while still in high school.

Administered by the College Board, a nonprofit organization, the AP program offered college-level courses to high school students in 37 different subjects in 2016, enabling students to earn credits toward high school diplomas and college degrees simultaneously. The College Board also administers AP exams that test students' mastery of course material.[2] Students who earn a passing score of 3 or higher out of 5 on an AP exam may be eligible to earn college credits, placement into more advanced college courses, or both, depending on the policy of the postsecondary institution they attend.

AP Exam Taking and Performance

Among mathematics and science AP exams, calculus AB has been the most common, followed by biology; both remained so in 2016, when approximately 308,000 high school students took the calculus AB exam and 238,000 took the biology exam (Table 1-20). Fewer students took more advanced exams (e.g., about 125,000 students took calculus BC). Physics C: electricity and magnetism was the least common exam, taken by approximately 23,000 students in 2016.

The number of high school students who took at least one AP exam nearly doubled in the past decade, from 1,464,254 in 2006 to 2,611,172 in 2016 (Table 1-21). To provide context, the overall high school population increased by just 9% between 2001 and 2013 (U.S. Department of Education 2015). Similarly, the number of students who took an AP exam in mathematics or science rose consistently across all subjects from 2006 to 2016, ranging from an increase of 36% in the number of students taking the calculus AB exam to an increase of 75% in the number of students taking the computer science A exam. Calculus AB, statistics, biology, and environmental science all saw gains of more than 100,000 students taking those exams over the decade. Passing rates for the mathematics and science exams ranged from lows of 40% for physics 1 and 46% for environmental science to highs of 77% for physics C: mechanics and 81% for calculus BC (Table 1-20).

TABLE 1-20

Students who took or passed an AP exam in high school, by subject: 2016

(Number and percent)

Subject	Number who took exam	Percentage who passed exam[a]
AP mathematics exam		
Calculus AB	308,215	59.5
Calculus BC	124,931	81.1
Statistics	206,563	60.9
AP science exam		
Biology	238,080	61.1
Chemistry	153,465	53.6
Computer science A	57,937	64.5
Environmental science	149,096	45.6
Physics 1	169,304	39.8
Physics 2	26,385	61.3
Physics C: electricity/ magnetism	23,347	70.5
Physics C: mechanics	53,110	77.4

AP = Advanced Placement.

[a] Students scoring 3, 4, or 5 on a scale of 1–5 for an AP exam were considered to have passed.

Source(s)

The College Board (2016), https://secure-media.collegeboard.org/digitalServices/pdf/research/2016/Student-Score-Distributions-2016.xls, accessed 16 March 2017.

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TABLE 1-21

Students taking AP exams, by subject: 2006 and 2016

(Number)

Subject	2006	2016
Any AP exam	1,464,254	2,611,172
AP mathematics exam		
Calculus AB	197,181	308,215
Calculus BC	58,603	124,931
Statistics	88,237	206,563
AP science exam		
Biology	131,783	238,080
Chemistry	87,465	153,465
Computer science A	14,662	57,937
Environmental science	44,698	149,096
Physics 1	NA	169,304
Physics 2	NA	26,385
Physics C: electricity/ magnetism and mechanics[a]	34,961	76,457

NA = not available; physics 1 and 2 exams were first offered in 2015.

AP = Advanced Placement.

[a] Physics C electricity/magnetism and mechanics are two different exams but were reported as combined totals by the College Board.

Source(s)

The College Board, https://secure-media.collegeboard.org/digitalServices/pdf/research/2016/2016-Exam-Volume-Change.xls, accessed 16 March 2017.

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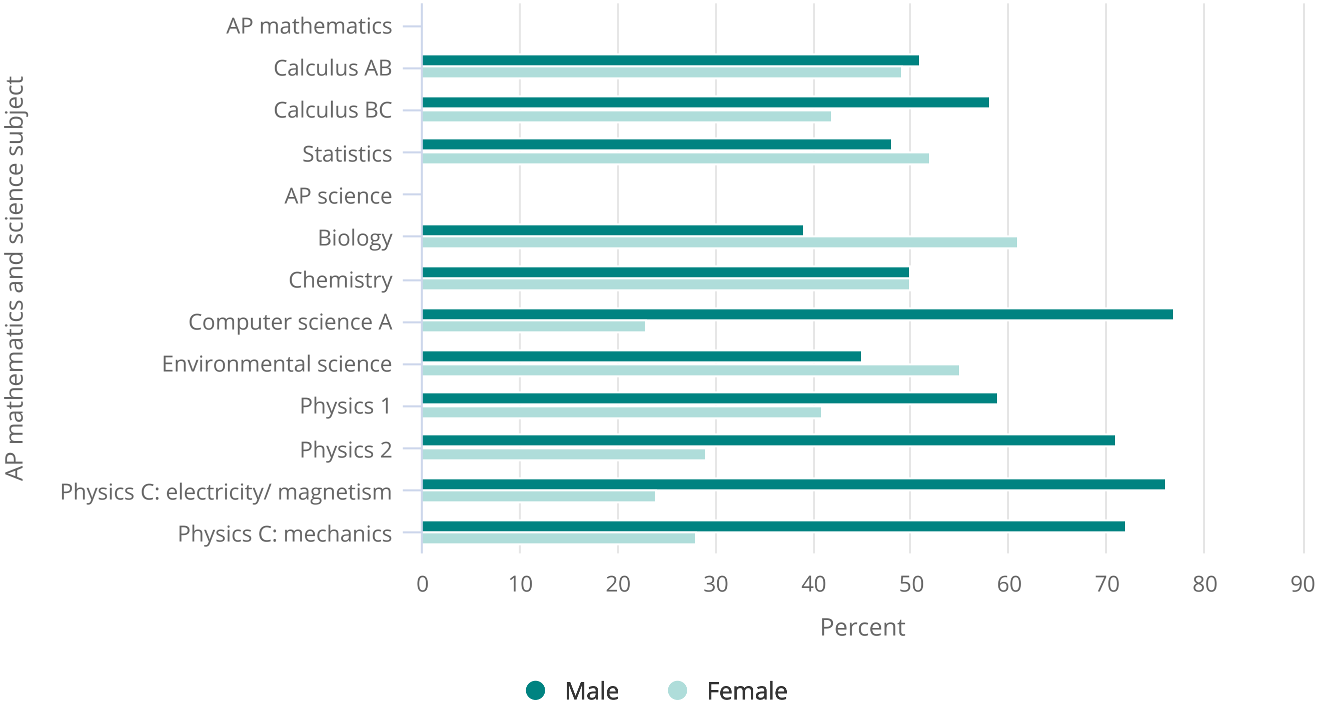
Sex. Mathematics and science AP exam taking varies by students' sex (Figure 1-6). Although the students who took calculus AB, statistics, and chemistry exams were about evenly split by sex in 2016, at advanced levels, male students predominated, representing 58% of all calculus BC takers, 71% of physics 2, 76% of physics C: electricity and magnetism, and 72% of physics C: mechanics. Male students also outnumbered their female counterparts in computer science, with 77% of computer science A exam takers being male students. In contrast, female students took a larger share of exams in biology (61%) and environmental science (55%).

FIGURE 1-6

Percentage distribution of high school students taking an AP exam in mathematics or science, by sex: 2016



AP = Advanced Placement.

Source(s)

The College Board, https://secure-media.collegeboard.org/digitalServices/misc/ap/national-summary-2016.xlsx, accessed 10 March 2017.

Science and Engineering Indicators 2018

Demographic Differences in Access to Advanced Mathematics and Science Courses: Civil Rights Data

The 2013–14 Civil Rights Data Collection (CRDC) is a survey of all public schools and school districts in the United States that is conducted by the Department of Education's Office for Civil Rights. The survey measures various factors that affect education equity and opportunity for students, including access to advanced mathematics and science courses (U.S. Department of Education 2016b). Overall, the CRDC shows that access to higher-level mathematics and science courses in the United States is not equal. Nationwide, 78% of high schools offer algebra 2, 48% offer calculus, 72% offer chemistry, and 60% offer physics (▦ Table 1-22). In addition, these data show that schools with high black and Latino enrollment offer less access to high-level mathematics and science courses than schools with low black and Latino enrollment.[3] For example, 56% of high schools with low black and Latino student enrollment offer calculus, compared with 33% of high schools with high black and Latino enrollment.

TABLE 1-22

Access to high-level mathematics and sciences courses among students at low versus high black and Latino enrollment schools: 2013–14

(Percent)

Course	All schools	Low black and Latino enrollment[a]	High black and Latino enrollment
Algebra II	78	84	71
Calculus	48	56	33
Chemistry	72	78	65
Physics	60	67	48

[a] "High/low black and Latino enrollment" refers to schools with more than 75% and less than 25% black and Latino student enrollment, respectively, as defined and reported by the U.S. Department of Education’s Office for Civil Rights.

Source(s)

U.S. Department of Education, Office for Civil Rights, *2013–2014 Civil Rights Data Collection: A first look* (2016). https://www2.ed.gov/about/offices/list/ocr/docs/2013-14-first-look.pdf, accessed 27 February 2017.

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[1] One credit is equivalent to a 1-year course of instruction.

[2] The cost of taking an AP exam was $93 per exam in 2017, a fee that might be prohibitive for low-income families and may affect equity of access to the exams. ESSA ended a federal grant program that had subsidized the cost of AP exams for students from low-income families for 17 years, adding to concerns about financial barriers to AP exam access. For more information, see https://www.edweek.org/ew/articles/2017/01/18/schools-grappling-with-fee-hikes-for-ap.html?r=1465832823.

[3] “High/low black and Latino enrollment” refers to schools with more than 75% and less than 25% black and Latino student enrollment, respectively, as defined and reported by the U.S. Department of Education’s Office for Civil Rights.

Teachers of Mathematics and Science

Students' achievement in mathematics and science depends not only on the courses they take, but also, in large part, on their access to high-quality instruction. Many factors may affect teacher quality, including qualifications, subject-matter knowledge, years of experience, ongoing professional development, access to instructional coaches, instructional resources and leadership, and working conditions. Educators and policymakers continue to focus on attracting and retaining high-quality STEM teachers, as evidenced by the inclusion in ESSA of multiple provisions related to STEM teachers (see sidebar ESSA and STEM Teachers).

SIDEBAR

ESSA and STEM Teachers

The Every Student Succeeds Act (ESSA) includes several provisions designed to help states and districts prepare, train, and recruit high-quality science, technology, engineering, and mathematics (STEM) teachers.* These provisions include the following:

Alternative certification allows states "to establish, expand, or improve alternative routes for state certification of teachers especially for teachers of ... science, technology, engineering, mathematics, or other areas where the state experiences a shortage of educators."

Differential pay allows states and districts to "provide differential pay, or other incentives, to recruit and retain teachers in high need academic subjects" such as STEM.

Use of block grants for STEM professional development allows states and districts to use state block grants "to develop and provide professional development and other comprehensive systems of support for teachers, principals, or other school leaders to promote high-quality instruction and instructional leadership in science, technology, engineering, and mathematics subjects, including computer science."

STEM master teacher corps enables the Secretary of Education to award grants to states to "support the development of a state-wide STEM master teacher corps."

Professional development in technology for STEM teachers stipulates that school districts receiving grants of $30,000 or more "to improve the use of technology to improve the academic achievement, academic growth, and digital literacy of all students" must spend a portion of those funds on allowable uses, which include "professional development in the use of technology to enable teachers and instructional leaders to increase student achievement in the areas of science, technology, engineering, and mathematics, including computer science."

* See http://www.stemedcoalition.org/2015/12/01/coalition-analysis-of-key-stem-provisions-in-esea-act/ for additional information. The full text of ESSA is available at https://www2.ed.gov/documents/essa-act-of-1965.pdf.

Science and Engineering Indicators 2016 (NSB 2016) provided in-depth analysis of STEM teachers using data from the NCES 2011–12 Schools and Staffing Survey (SASS). New national data on STEM teachers have not become available since the publication of *Science and Engineering Indicators 2016*,[1] so this section provides a brief review of those findings followed by new data that provide insight into how U.S. teachers' salaries compare with those of their international counterparts.

As noted, the primary data source for STEM teacher information for *Science and Engineering Indicators 2016* was the 2011–12 SASS, a national survey conducted biennially by NCES from 1987 to 2011. NCES has redesigned SASS and launched it as a new survey, the National Teacher and Principal Survey (NTPS). Data collection began during the 2015–16 school year, and data will be available for analysis by 2018. NTPS was designed to be more flexible, timely, and integrated with other Department of Education surveys. It covers the same core topics as SASS while also including newer topics, such as teachers' use of information technology in the classroom. Core topics include teacher and principal preparation, school characteristics, demographics of the teacher and principal labor force, teacher professional development, and teacher compensation and retention.

Previous Findings

Science and Engineering Indicators 2016 provided various indicators of public school mathematics and science teachers' quality based on data collected during the 2011–12 school year, including educational attainment, professional certification, participation in student teaching, self-assessment of preparation, and years of experience. The section on mathematics and science teachers also examined school factors, such as salary and working conditions, that may affect teacher effectiveness. The section focused on middle and high school teachers because mathematics and science teachers are more common and more easily identified at these levels than at the elementary level.

In 2011, the vast majority of public middle and high school mathematics (91%) and science (92%) teachers were fully certified (i.e., held regular or advanced state certification). The percentage of mathematics and science teachers with full state certification increased by 6 percentage points and 9 percentage points, respectively, from 2003 to 2011. The increase in teachers with full certification was seen in many types of schools but was more apparent among science teachers in high-minority (from 79% in 2003 to 90% in 2011) and high-poverty schools (from 80% to 91%). Despite these increases, fully certified mathematics and science teachers were still less prevalent in high-minority and high-poverty schools when compared with low-minority and low-poverty schools. For example, 88% of mathematics teachers in high-poverty schools were fully certified, compared with 95% of those in low-poverty schools.

The prevalence of mathematics and science teachers with degrees in the subject they taught (i.e., in-field degrees) also varied by school poverty level. For example, 75% of middle school mathematics teachers in low-poverty schools had in-field degrees, compared with 63% of teachers at high-poverty schools. At the high school level, 95% of mathematics teachers at low-poverty schools had in-field degrees, compared with 87% at high-poverty schools.

Although the percentage of mathematics teachers with more than 20 years of experience decreased from 29% in 2003 to 23% in 2011, the percentage of teachers with 10–19 years of experience increased from 27% to 33%, and the percentage of teachers with fewer than 3 years of experience decreased from 19% to 15%. The pattern among science teachers was similar. Overall, in 2011, 85% of public middle and high school mathematics teachers and 90% of science teachers had more than 3 years of experience. The percentage of mathematics teachers with fewer than 3 years of experience was higher at high-poverty schools, however, compared with low-poverty schools (18% versus 10%). The pattern was similar for science teachers.

In 2011, the average base salary of middle and high school teachers was approximately $53,000 for mathematics teachers and $54,000 for science teachers, according to teachers' reports in SASS. When asked to rate their satisfaction with their salaries, slightly more than half of mathematics teachers, and just under half of science teachers, reported being satisfied. Teachers at high-poverty schools earned less than their counterparts at low-poverty schools, with mathematics teachers earning $10,000 less and science teachers earning $13,000 less on average.

International Comparisons of Teacher Salaries

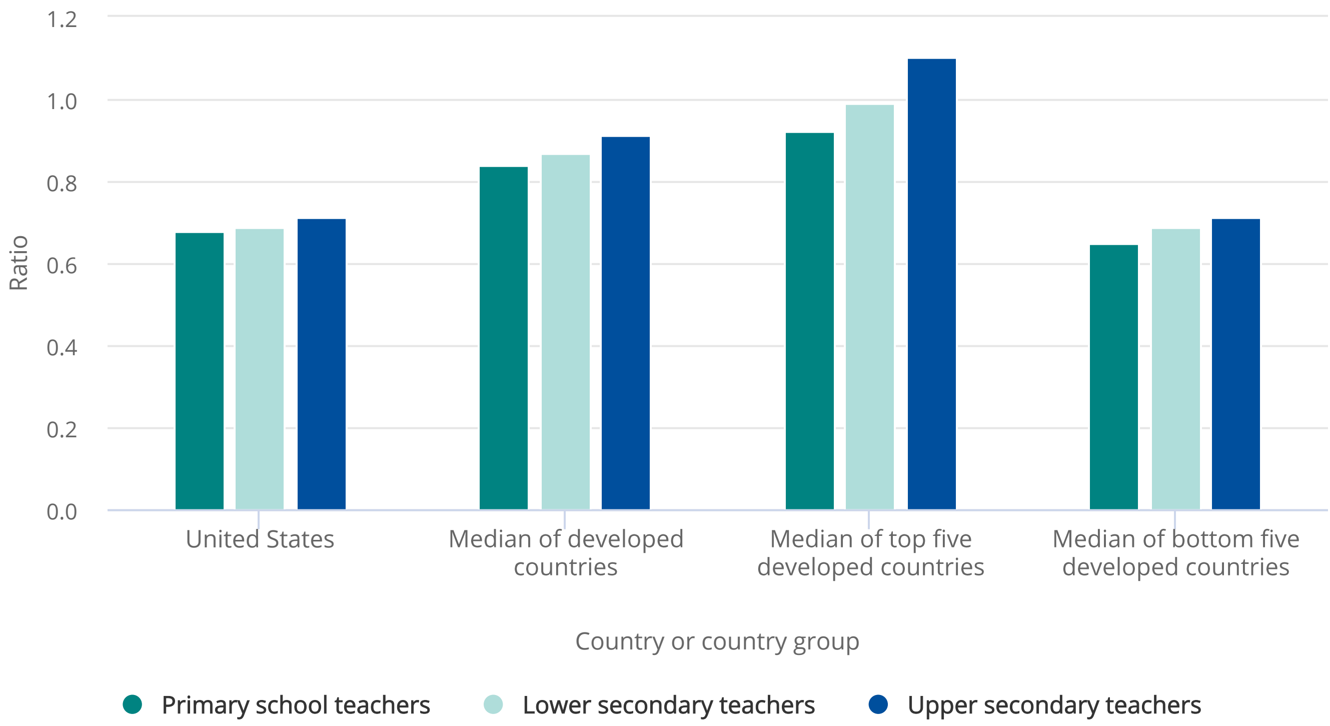
Teachers' salaries are associated with the attractiveness of teaching as a profession. The relative earnings in teaching and nonteaching professions correlate with career choices, and there is less attrition among teachers with higher salaries (Feng 2014; Gilpin 2012; James et al. 2011; OECD 2005).

The United States ranks low among developed countries with respect to the ratio of teachers' salaries to the salaries of other tertiary educated workers. For primary school teachers, the U.S. ranking is 20th of 23 countries. For lower and upper secondary school teachers, the United States is 21st of 23 countries.

📊 Figure 1-7 examines the ratio of teachers' salaries to the salaries of other tertiary educated workers, comparing these ratios across developed countries. Primary teachers in the United States make 68% of the salary of other tertiary educated workers—that is, a 0.68 ratio. Lower secondary teachers (middle or junior high school) have a ratio of 0.69, whereas upper secondary teachers have a ratio of 0.71. The median relative salary ratio for all 23 developed countries for which data were available ranged from 0.84 to 0.91 for the three education levels. For the top five developed countries, the relative salary ratio ranged from 0.92 to 1.10.

FIGURE 1-7

Salaries of teachers in developed countries relative to earnings for tertiary educated workers: 2014



Note(s)

Education level defined by United Nations Educational, Scientific and Cultural Organization's *International Standard Classification of Education*, 2011. Lower secondary corresponds to junior high school or middle school in the United States. Thirty-two Organisation for Economic Co-operation and Development countries are defined as developed according to the International Monetary Fund's "advanced economy" classification. Of these, the data here reflect 23 developed countries for which data were available.

Source(s)

Organisation for Economic Co-operation and Development, *Education at a Glance: OECD Indicators*, 2016.

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A shortcoming of these data is that they are not adjusted for the level of tertiary education teachers and nonteachers received. For example, if U.S. teachers received fewer years of tertiary education than teachers in other countries, this may help account for some of the salary differences between countries. The OECD, however, provides some data that address this potential shortcoming. Ratios adjusted for amount of tertiary education are available for 11 developed countries, including the United States (OECD 2016). The United States, however, fares worse once the amount of tertiary education is considered: the gap between the U.S. ratio and the average ratio for other countries grows. In short, the ratio of teacher salaries to those of other educated workers is not lower in the United States than in other countries because U.S. teachers receive fewer years of tertiary education.

Another shortcoming of these data is that they do not focus specifically on science and mathematics teachers. However, salaries in the United States for K–12 teachers whose primary focus in teaching is mathematics or science were only 1.7% higher than salaries for other teachers.[2] This suggests that gaps in relative salaries for mathematics and science teachers might be similar to those observed for other teachers.

In summary, U.S. K–12 teachers have lower salaries than other U.S. workers with tertiary education, and the ratio of U.S. K–12 teacher salaries to that of other U.S. tertiary educated workers is smaller than for that of the median OECD country. Although U.S. K–12 teachers make 68% to 71%—depending on grade level—of the salary of other workers with tertiary education, the median for OECD countries ranges from 84% to 91%.

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[1] The Teachers of Mathematics and Science section from *Science and Engineering Indicators 2016* can be accessed at https://www.nsf.gov/statistics/2016/nsb20161/#/report/chapter-1/teachers-of-mathematics-and-science.

[2] Special tabulations (2016) using Schools and Staffing Survey PowerStats tool are available at https://nces.ed.gov/datalab/sass/.

Instructional Technology and Digital Learning

Over the years, policymakers and researchers have suggested that modern technology may have the potential to transform education (Duffey and Fox 2012; Johnson et al. 2014; U.S. Department of Education 2016a). Recognizing the potential value of technology, the U.S. federal government has launched a series of initiatives in recent years urging school leaders and educators across the nation to adopt a 21st-century model of education that encompasses technology. In 2013, then-President Obama announced the ConnectED initiative, pledging to connect 99% of American students to next-generation broadband and high-speed wireless in their schools and libraries by 2018. The country has made significant progress in reaching this goal, with the percentage of school districts with high-speed broadband increasing from 30% in 2013 to 88% in 2016 (Education Superhighway 2017). Many states have also joined the federal efforts, taking an active role in building a technology-rich learning environment in their states (Education Superhighway 2017; Watson et al. 2014).

Technology integration in schools not only provides access to the Internet but also encompasses the use of technological tools and practices, including online courses, use of various devices and hardware in classrooms, computer-based assessment, and adaptive software for students with special needs. Collectively referred to as instructional technology, this wide range of tools and practices involves using and creating appropriate technological processes and resources to facilitate teaching, engage students, and improve learning outcomes (Alliance for Excellent Education 2011; Richey 2008).

Data and research about instructional technology are presented in two sections. The first section focuses on the availability or use of various technological devices in classrooms and other topics such as Internet access. The second section focuses on online learning, providing data about its prevalence and the different types of online learning available to students. Each section concludes with a review of the research on the effectiveness of the technology discussed and its impact on student learning outcomes.

Technology as a K–12 Instructional Tool

The use of instructional technology—computers, the Internet, mobile devices, interactive whiteboards, and other emerging technologies—in K−12 classrooms has been growing rapidly. However, national data available to address the quality and effectiveness of the technologies remain limited, and research has generally shown only modest positive effects of technology on learning (Snyder and Dillow 2013; U.S. Department of Education 2016a).

Computers and Other Technology Devices

Computers are universally available in U.S. elementary and secondary schools (NSB 2014); however, as discussed later in this section, some K–12 teachers do not consider the current availability of instructional technology to be adequate, particularly in science classes. As of 2008, all U.S. public K–12 schools had one or more computers for instructional purposes on campus (Gray, Thomas, and Lewis 2010a). Computers are also commonly available in classrooms. In 2009, for example, 97% of K–12 public school teachers reported that they had one or more computers in their classroom, and 69% said that they or their students often or sometimes used computers during class time (Gray, Thomas, and Lewis 2010b). In addition to computers, the majority of teachers reported having the following technology devices available as needed or in the classroom every day: liquid crystal display or digital light processing projectors (84%), digital cameras (78%), and interactive whiteboards (51%). Furthermore, increasing numbers of schools and districts have initiated one-to-one computing programs, giving each student a laptop, tablet computer, or other mobile computing device to connect to the Internet, access digital course materials and textbooks, and complete school assignments (Gemin et al. 2015).

Despite the availability of computers and other devices in classrooms, many teachers still believe they lack technology resources. According to a 2012 national survey conducted by Project Tomorrow, 55% of K–12 teachers reported that there were not enough computers for student use in their classes, highlighting this deficiency as one of the major obstacles in their use of technology for teaching (Project Tomorrow 2013).

The lack of technology resources in classrooms may be more common in science classes than in mathematics classes. The 2012 National Survey of Science and Mathematics Education sponsored by the National Science Foundation found that, although 69% of elementary, middle, and high school mathematics teachers indicated that their instructional technology resources were adequate, just 34% to 48% of elementary, middle, and high school science teachers indicated so (Banilower et al. 2013).

Internet Access

Access to the Internet is universal in public K–12 schools in the United States. As of 2008, all public schools had instructional computers with an Internet connection (Gray, Thomas, and Lewis 2010a). Although Internet access at schools is universal, access with adequate bandwidth and connection speeds remains an area of concern. However, substantial progress is being made (Consortium for School Networking [CoSN] 2016; Education Superhighway 2017). In a 2016 national survey of school district technology administrators, more than two-thirds (68%) indicated that all the schools in their system fully met the Federal Communication Commission's short-term minimum Internet bandwidth recommendations for public schools,[1] up from 19% in 4 years (CoSN 2016). Affordability, network speed, capacity, reliability, and competition continue to affect Internet connectivity. Survey results suggest that increased bandwidth continues to be needed because schools expect dramatic increases in the number of students using multiple devices for classwork while at school. In 2016, 21% of schools reported that their students were using two or more devices per day; 65% of respondents expect use of two or more devices per student per day within the next 3 years (CoSN 2016).

Despite the progress that has been made in connectivity, access to high-speed Internet connections continue to vary by student demographics. One study reported that students in high-minority schools were half as likely to have high-speed Internet as students in low-minority schools, and students in low-income schools or remote rural areas were twice as likely as students in affluent schools or their urban and suburban peers to have slow Internet access at their schools (Horrigan 2014).

Mobile Devices

In addition to computers, mobile devices such as laptops, smartphones, and tablets are enhancing students' access to the Internet. Even though these Internet-connected devices have become one of the primary means with which youth interact and learn from each other, few national data are available to describe how and with what frequency these devices are used in day-to-day learning in and out of school. One extensive, although not nationally representative survey conducted by Project Tomorrow (2015),[2] found that 47% of K–12 teachers reported that their students had regular access to mobile devices in their classrooms. In terms of which types of devices students used for schoolwork during the school day, the survey found that 58% of students used their own device, followed by school laptops (32%), school Chromebooks (16%), and school tablets (14%) (Project Tomorrow 2015). Overall, 13% of high school and 21% of middle school students reported no access to computers or mobile devices at school (Project Tomorrow 2015).

Digital Conversion

With the advent of Internet-connected mobile devices, schools and districts are also initiating what is called a digital conversion within their classrooms, replacing traditional hard-copy textbooks with interactive, multimedia digital textbooks or e-textbooks that are accessible to students through the Internet. Forty-six percent of students in grades 9–12 who responded to Project Tomorrow's 2015 survey reported that they were using online textbooks, compared with 30% in 2005 (Project Tomorrow 2016). Educators are also supplementing traditional resources with videos, games, simulations, and other Internet-based resources. The use of academic-content videos from such services as YouTube, Khan Academy, and the National Aeronautics and Space Administration, among others, is growing as well. In the Project Tomorrow 2015 survey, 68% of teachers (up from 47% in 2012) reported that they regularly use videos from the Internet to augment their class lessons and stimulate class discussion (Project Tomorrow 2016). Students also report accessing Internet videos for support with homework, research projects, and other learning, with science (66%) and mathematics (59%) topping the list of content accessed. The use of computer games to supplement classroom learning is also on the rise, with 48% of teachers in 2015 reporting that they used them in their classrooms, up from 30% in 2012.

Research on Effectiveness of K–12 Instructional Technology

Effects of Instructional Technology

Existing research studies about the effects of instructional technology on student learning are not comprehensive enough to address the general question of whether technology improves student outcomes (Tamim et al. 2011). Few national studies are available; many of the existing studies are of brief duration or are based on specific products with small and geographically narrow samples or weak research designs. Nevertheless, some meta-analyses—studies that seek to combine data from nonrepresentative studies into a rigorous statistical design to provide limited but more rigorous findings—have yielded findings that suggest modest positive effects of technology on student learning.

One recent meta-analysis explored the effect of one-to-one laptop computing programs on elementary and secondary student achievement (Zheng et al. 2016). Drawing on articles published between 2001 and 2015, this study reviewed 96 articles but only found 10 suitable for inclusion in the statistical analysis, suggesting that rigorous research about the effects of one-to-one computing remains limited. The study found that one-to-one laptop programs had a modest effect on students' overall academic achievement in mathematics and science (Zheng et al. 2016). These findings are aligned with the findings from an earlier large-scale meta-analysis of all types of computer use in classrooms, which summarized 1,055 primary studies from 1967 to 2008 and concluded that the use of computer technologies in classrooms had modest effects on student achievement (Tamim et al. 2011).

Three meta-analyses that specifically focused on mathematics learning compared the mathematics achievement of students taught in elementary and secondary classes using technology-assisted mathematics programs with that of students in control classes using alternative programs or standard methods (Cheung and Slavin 2011; Li and Ma 2010; Rakes et al. 2010). All three studies found small, positive effects on student achievement when technology was incorporated into mathematics classes. A randomized impact evaluation found that a computer-aided application improved elementary students' mathematics test scores (Carrillo, Onofa, and Ponce 2010). A more recent randomized field trial of seventh grade mathematics students also found that an online mathematics homework tool combined with teacher training led to higher mathematics achievement scores for participating students compared with those of a control group that did not have access to the program (Roschelle et al. 2016).

Some studies also suggest that technology's potential to improve student achievement may depend on how it is incorporated into instruction (Cennamo, Ross, and Ertmer 2013; Ross, Morrison, and Lowther 2010; Tamim et al. 2011). One study found that, when computing devices were used as tools to supplement the traditional curriculum, no increase in achievement was observed; when computing devices were used as the main teaching tools in class, however, student achievement increased (Norris, Hossain, and Soloway 2012).

K–12 Online Learning

In addition to its potential for enhancing learning in the classroom, technology can also enable students to access instruction remotely via the Internet. Online learning at the K–12 level ranges from programs that are fully online with all instruction occurring via the Internet to hybrid or blended learning programs that combine face-to-face teacher instruction with online components (Gemin et al. 2015; Watson et al. 2014). Online learning discussed in this section focuses on fully online schools and stand-alone online courses that do not incorporate face-to-face instruction.

In the 2014–15 school year, 24 states operated virtual schools that offered supplemental online courses for students. These schools served more than 462,000 students, who took a total of 815,000 online semester-long courses (Gemin et al. 2015). Although still a small fraction of the approximately 50 million students enrolled in K–12 public schools, this was a significant increase since 2012–13, when 721,149 semester course enrollments were recorded. High school students took most of these courses (85%). Math courses made up nearly 23% of the courses taken, and science courses made up 14% (Gemin et al. 2015). Full-time virtual charter schools are another online option for students; these schools served about 275,000 students during the 2014–15 school year (Gemin et al. 2015).

A nationally representative survey of public school districts conducted by NCES in 2009 found that the top reasons for offering online learning opportunities were to provide courses not otherwise available at their schools (64%) and to give students opportunities to recover course credits from classes missed or failed (57%) (Queen and Lewis 2011). The survey also found that credit recovery was especially important in urban areas, where 81% of school districts indicated that this was a very important reason for making online learning opportunities available. Other reasons school districts gave for providing online learning options included offering AP or college-level courses (40%), reducing scheduling conflicts for students (30%), and providing opportunities for homebound students and those with special needs (25%).

Research on Effectiveness of Online Learning

Effects of Online Learning

Policymakers and researchers cite many potential benefits of online learning, which include increasing access to resources, personalizing learning, and assisting struggling students (Bakia et al. 2012; Watson et al. 2013). Despite these potential benefits, few rigorous national studies have addressed the effectiveness of online learning compared with that of traditional teaching models at the K–12 level. One rigorous, large-scale national study of virtual charter schools was conducted by the Center for Research on Education Outcomes (CREDO), housed at Stanford University (CREDO 2015). Researchers contrasted the annual academic growth of students attending full-time online charter schools with that of a comparison group of students from traditional schools who were similar in terms of grade level, sex, race or ethnicity, poverty, prior test scores, and other attributes. The study found that students attending the online schools in the 2012–13 school year had significantly weaker academic growth when compared with their counterparts at traditional schools (CREDO 2015). These results, however, were specific to online charter schools and do not apply to full-time online schools operated by states and districts or to individual online course enrollments or blended learning school models.

A common use of online learning courses is to allow students to recover credits from courses they have failed. One large study comparing achievement outcomes for students taking an algebra credit recovery course online with students taking a face-to-face course found weaker achievement outcomes for students taking the online course (Heppen et al. 2017). Other recent studies have observed some positive effects for online learning, but researchers stress that teacher training and the way in which online components are integrated into the curriculum are important variables that could affect outcomes and that need to be the subject of more rigorous research (Barbour 2015). Although the latest research suggests that online schools may be meeting the needs of students who do not have access to adequate physical school and course options, research on the effectiveness of online learning is still in a nascent state (Watson et al. 2014).

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[1] The Federal Communication Commission short-term goal is 100 Mbps per 1,000 students. The long-term goal is 1 Gbps per 1,000 students.

[2] The global education nonprofit, Project Tomorrow, conducts the annual Speak Up Research Project, which polls K–12 students, parents, and educators about the role of technology in learning in and out of school. In fall 2014, Project Tomorrow surveyed 431,231 K–12 students, 35,337 parents, 41,805 teachers, 680 district administrators, and 3,207 school administrators representing 8,216 public and private schools from 2,676 districts. Schools from urban (30%), suburban (30%), and rural (40%) communities were represented. Just over one-half of the schools (56%) that participated in Speak Up 2014 were Title I eligible schools (an indicator of student population poverty). In fall 2015, Project Tomorrow surveyed 415,686 K–12 students, 38,613 teachers and librarians, 4,536 administrators, and 40,218 parents representing more than 7,600 public and private schools and 2,600 districts. Schools from urban (25%), suburban (40%), and rural (35%) communities were represented. Just over one-half of the schools (58%) that participated in Speak Up 2015 were Title I–eligible schools.

Transition to Higher Education

One of the most important education goals in the United States is to educate every student to graduate from high school ready for college and a career (Achieve Inc. 2016; NCEE 2013; Pellegrino and Hilton 2012). Over the past decades, U.S. high school graduation rates have been rising steadily, reaching 83% in 2015 (McFarland, Stark, and Cui 2016). Although high school completion represents a major milestone for adolescents, most of today's fastest-growing, well-paying jobs require at least some postsecondary education (Carnevale, Smith, and Strohl 2010; Hout 2012). Young people who do not pursue education beyond high school face fewer job opportunities, lower earnings, and a greater likelihood of being unemployed and underemployed than their college-educated peers (Baum, Ma, and Payea 2013; Pew Research Center 2014).

Within this context, this section focuses on indicators related to U.S. students' transitions from high school to postsecondary education. It presents national data on on-time high school graduation rates, trends in immediate college enrollment after high school, choice of STEM majors at the postsecondary level, and academic preparation for college. This section also examines U.S. students' high school graduation rates relative to those of their peers in other countries. Together, these indicators present a broad picture of the transition of U.S. students from high school to postsecondary education. (Higher education in S&E is the topic of Chapter 2.)

Completion of High School

Estimates of U.S. high school completion rates vary, depending on the definitions, data sources, and calculation methods (Heckman and LaFontaine 2007; Seastrom et al. 2006). Based on a relatively inclusive definition—receiving a regular high school diploma or earning an equivalency credential, such as a GED certificate—about 92% of the U.S. population ages 18–24 in 2013 had completed a high school education (McFarland, Stark, and Cui 2016). This is largely consistent with the experience of a nationally representative cohort of 2002 high school sophomores; 96% of the cohort members had earned a high school diploma or an equivalency credential by 2012 (Lauff and Ingels 2014).

Beginning with the 2010–11 school year, the Department of Education required all states to use a more restrictive definition of high school graduation, emphasizing on-time completion and considering only recipients of regular high school diplomas (Chapman et al. 2011). Using this definition, NCES releases two annual measures of high school completion: the Adjusted Cohort Graduation Rate (ACGR) and the Averaged Freshman Graduation Rate (AFGR).[1] Both measures provide the percentage of public school students who attain a regular high school diploma within 4 years of starting ninth grade, but the ACGR is the more accurate measure because it relies on longitudinal data that track each student over time (McFarland, Stark, and Cui 2016). The U.S. high school graduation rates discussed below are ACGRs.[2]

On-Time Graduation Rates from 2011 to 2015

The on-time graduation rate among U.S. public high school students has increased steadily since 2011 (Table 1-23). In 2011, 79% of public high school students graduated on time with a regular diploma; by 2015, the percentage had climbed to 83%.

Socioeconomic status. In addition to reporting graduation rates by race or ethnicity to the federal government, states also report rates by students who are economically disadvantaged.[3] Although on-time graduation rates for economically disadvantaged students have improved by 6 percentage points since 2011, these students continue to graduate at lower rates than the general population (76% versus 83%).

Race or ethnicity. Black students made the largest gain during this period, an improvement of 8 percentage points, from 67% in 2011 to 75% in 2015. Hispanic students made a gain of 7 percentage points, from 71% in 2011 to 78% in 2015, as did

American Indian or Alaska Native students, from 65% in 2011 to 72% in 2015. White students gained 4 percentage points, and Asian or Pacific Islander students gained 3 percentage points during this period. Despite this improvement, substantial differences among racial and ethnic groups persisted: in 2015, the on-time high school graduation rates for Asian or Pacific Islander and white students were 90% and 88%, respectively; and both rates surpassed those of black, Hispanic, and American Indian or Alaska Native students (72%–78%) by at least 16 percentage points.

TABLE 1-23

On-time graduation rates of U.S. public high school students, by student characteristics: 2011−15

(Percent)

Characteristic	2011	2012	2013	2014	2015
All students	79	80	81	82	83
Race or ethnicity[a]					
White	84	86	87	87	88
Black	67	69	71	73	75
Hispanic	71	73	75	76	78
Asian or Pacific Islander	87	88	89	89	90
American Indian or Alaska Native	65	67	70	70	72
Economically disadvantaged[b]	70	72	73	75	76
Limited English proficiency[c]	57	59	61	63	65
Students with disabilities[d]	59	61	62	63	65

[a] Hispanic may be any race. American Indian or Alaska Native, Asian or Pacific Islander, black, and white refer to individuals who are not of Hispanic origin.

[b] This refers to students who met the reporting states' criteria for classification as economically disadvantaged.

[c] This refers to students who met the definition of limited English proficient as outlined in the ED*Facts* Workbook. For more information, see appendix B in https://www2.ed.gov/about/inits/ed/edfacts/eden/16-17-workbook-13-0.pdf.

[d] These students were identified as children with disabilities under the Individuals with Disabilities Education Act.

Source(s)

McFarland J, Stark P, Cui J, *Trends in High School Dropout and Completion Rates in the United States: 2013,* NCES 2016 117 (2016); U.S. Department of Education, National Center for Education Statistics, Common Core of Data data tables, https://nces.ed.gov/ccd/tables/ACGR_RE_and_characteristics_2013-14.asp and https://nces.ed.gov/ccd/tables/ACGR_RE_and_characteristics_2014-15.asp, accessed 27 February 2017.

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High School Graduation Rates in the United States and Other OECD Nations

The OECD estimates upper secondary graduation rates for its members and selected nonmember countries by dividing the number of graduates in a country in a specific year by the number of people at the typical graduation age (OECD 2016).[4] These estimates enable a broad, albeit imperfect, comparison between the United States and other countries.[5] Based on 2014 data, U.S. graduation rates are lower than those of many OECD countries. Among the 25 OECD nations with available data on graduation rates in 2014, the United States ranked 19th, with a graduation rate of 82%, compared with the OECD average of 85% (▦ Table 1-24). The top-ranked countries, listed in order of rank, are Finland, Japan, New Zealand, Netherlands, South Korea, Denmark, Italy, Germany, and Slovenia—all of which had graduation rates of 90% or higher.

Furthermore, the relative standing of U.S. high school graduation rates has stayed largely the same from 2008 to 2014. Among the 18 OECD countries for which graduation rate data were available in 2008, 2010, 2012, and 2014, the United States ranked 13th in 2008, 14th in 2010 and 2012, and 12th in 2014 (▦ Table 1-25).

TABLE 1-24

High school graduation rates, by OECD country: 2014

(Percent)

Country	High school graduation rate
OECD average[a]	85.4
Finland	96.9
Japan	96.7
New Zealand	95.5
Netherlands	94.8
South Korea	94.6
Denmark	94.0
Italy	93.0
Germany	90.7
Slovenia	90.0
Austria	89.7
Israel	89.6
Iceland	89.3
Canada[b]	88.7
Hungary	87.8
Chile	87.7
Norway	84.3
Slovakia	82.6
Poland	82.5
United States	81.9
Spain	74.4
Czech Republic	74.0
Luxembourg	73.9
Sweden	68.7
Turkey	67.6

Country	High school graduation rate
Mexico	51.3

OECD = Organisation for Economic Co-operation and Development.

[a] OECD average is based on all OECD countries with available data.

[b] Graduation rate is for 2013.

Note(s)

To generate estimates that are comparable across countries, OECD calculated high school graduation rates by dividing the number of first-time graduates (of any age) completing upper secondary education programs in the country by the population of the typical graduation age, which OECD refers to as the age of the students at the beginning of the school year (e.g., 17 years old in the United States). Countries are ordered by 2014 high school graduation rate.

Source(s)

OECD, *Education at a Glance: OECD Indicators 2016* (2016).

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TABLE 1-25

Relative standing of U.S. high school graduation rates among OECD countries: 2008, 2010, 2012, and 2014

(Percent)

Year	OECD country	High school graduation rate
2008	Germany	97
	Japan	95
	Finland	93
	South Korea	93
	Norway	91
	Iceland	89
	Czech Republic	87
	Italy	85
	Denmark	83
	Poland	83
	Slovakia	81
	Hungary	78
	United States	77
	Sweden	76
	Luxembourg	73
	Spain	73
	Mexico	44
	Turkey	26
2010	Japan	96
	South Korea	94
	Finland	93
	Iceland	88
	Germany	87
	Norway	87

Year	OECD country	High school graduation rate
	Denmark	86
	Hungary	86
	Slovakia	86
	Poland	84
	Italy	83
	Spain	80
	Czech Republic	79
	United States	77
	Sweden	75
	Luxembourg	70
	Turkey	54
	Mexico	47
2012	Germany	95
	Iceland	95
	Hungary	94
	Finland	93
	Japan	93
	Spain	93
	Denmark	92
	South Korea	92
	Norway	88
	Slovakia	86
	Poland	85
	Italy	84
	Czech Republic	82
	United States	79
	Sweden	77

Year	OECD country	High school graduation rate
	Luxembourg	69
	Turkey	55
	Mexico	47
2014	Finland	97
	Japan	97
	South Korea	95
	Denmark	94
	Italy	93
	Germany	91
	Iceland	89
	Hungary	88
	Norway	84
	Poland	83
	Slovakia	83
	United States	82
	Czech Republic	74
	Luxembourg	74
	Spain	74
	Sweden	69
	Turkey	68
	Mexico	51

OECD = Organisation for Economic Co-operation and Development.

Note(s)

Data include only OECD countries with available data in all 4 years. Countries whose percentages are tied are listed alphabetically.

Source(s)

Organisation for Economic Co-operation and Development, *Education at a Glance: OECD Indicators 2008* (2008), *Education at a Glance: OECD Indicators 2010* (2010), *Education at a Glance: OECD Indicators 2012* (2012), and *Education at a Glance: OECD Indicators 2014* (2014).

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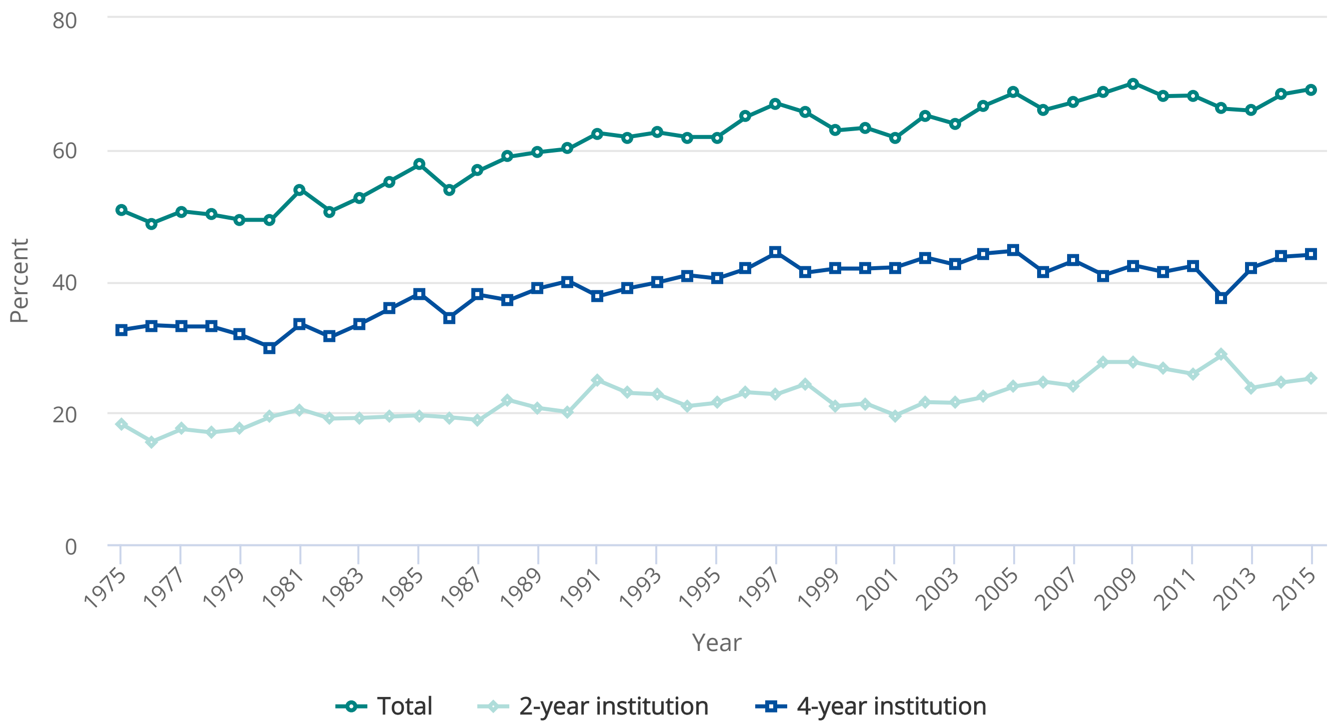
Enrollment in Postsecondary Education

After completing high school, some students immediately enter the workforce, join the military, or start families, but the majority go directly into postsecondary education (Ingels et al. 2012). Of the 3 million students who completed high school or a GED in 2015, some 2.1 million (69%) enrolled in a 2- or 4-year college the following fall (Kena et al. 2016). This rate, known as the immediate college enrollment rate, is defined as the annual percentage of high school completers aged 16 to 24, including GED recipients, who enroll in 2- or 4-year colleges by the October after high school completion.

Between 1975 and 2015, the percentage of high school graduates making an immediate transition to college increased from 51% to 69% (Figure 1-8). In each year, more students enrolled in 4-year institutions than in 2-year institutions. Immediate enrollment rates between 1975 and 2015 increased from 33% to 44% for 4-year institutions and from 18% to 25% for 2-year institutions.

FIGURE 1-8

Immediate college enrollment rates among high school graduates, by institution type: 1975–2015



Note(s)

The figure includes students ages 16 to 24 who completed high school in each survey year. Immediate college enrollment rates are defined as rates of high school graduates enrolled in college in October after completing high school. Before 1992, high school graduates referred to those who had completed 12 years of schooling. As of 1992, high school graduates are those who have received a high school diploma or equivalency certificate. Detail may not sum to total due to rounding.

Source(s)

The Condition of Education, tables 302.10, 302.20, 302.30, https://nces.ed.gov/programs/coe/indicator_cpa.asp, accessed 3 May 2017. See Appendix Table 1-27.

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Socioeconomic status. Enrollment gaps, however, persisted among students of different socioeconomic backgrounds (Appendix Table 1-27): in 2015, the immediate college enrollment rate of students from low-income families was lower than the rate of those from high-income families (69% versus 83%).

Race or ethnicity. Since 1975, the immediate college enrollment rate has increased from 49% to 70% for white students, 45% to 63% for black students, and 53% to 67% for Hispanic students. Asians or Pacific Islanders enrolled at consistently higher rates than all other groups since 2003, when data on Asian and Pacific Islander students were first available.

Sex. The immediate college enrollment rate in 2015 was higher for female students (73%) than for male students (66%).

Other characteristics. Enrollment rates also varied widely with parental education, ranging in 2015 from 56% for students whose parents had less than a high school education to 82% for students whose parents had a bachelor's or higher degree.

Preparation for College

Although the majority of U.S. students attend college after high school, high rates of remedial coursetaking and low rates of college completion indicate that many of them are not well prepared during their high school years for college (Chen 2016). Research indicates that many college students arrive on campus lacking the necessary academic skills to perform at the college level. Postsecondary institutions address this problem by offering remedial courses designed to strengthen students' basic skills. Students must pass these remedial courses before they can begin taking credit-bearing courses that count toward their degree. In 2011–12, about 29% of students at public 4-year institutions and 41% at public 2-year institutions reported having ever taken remedial courses (Skomsvold 2014).

In 2016, Achieve Inc., an independent, nonprofit education reform organization, conducted the first state-by-state analysis of student performance on college- and career-ready measures (including performance on assessments, completion of a rigorous course of study, and earning college credit while in high school) and determined that "too few high school graduates are prepared to succeed in postsecondary education" (Achieve Inc. 2016: 1). Student scores on such assessments as NAEP and ACT also suggest that a majority of high school students are not academically prepared for college-level mathematics and science coursework (see sidebar Measuring College Readiness in Mathematics and Science).

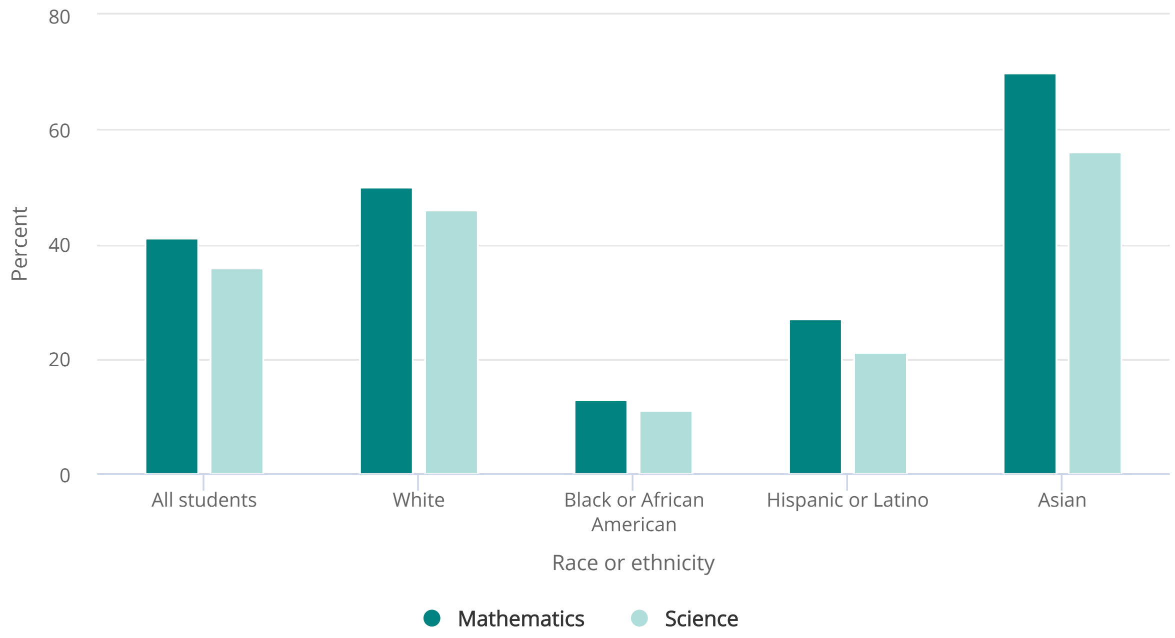
SIDEBAR

Measuring College Readiness in Mathematics and Science

The ACT is a national college admissions examination that consists of subject-area tests in English, mathematics, reading, and science. In 2016, 64% of the high school graduating class took the ACT (ACT 2016). The ACT organization has established College Readiness Benchmarks, which are the minimum scores students need to have a high probability of success in the credit-bearing college courses most commonly taken by first-year college students.* ACT drew on college performance data from 214 institutions and 230,000 students to establish its benchmarks. Although not representative of the entire high school population, performance on these benchmarks gives insight into how well prepared a majority of the nation's students are to succeed in college-level mathematics and science. In 2016, ACT reported that 41% of ACT takers met the college readiness benchmark in mathematics, and 36% met the college readiness benchmark in science (Figure 1-A). These percentages varied substantially by race or ethnicity, with 70% of Asian ACT takers meeting the mathematics benchmark, compared with 50% of white students, 27% of Hispanic students, and 13% of black students. Similar disparities were seen in the percentages of students meeting the science benchmark, with 56% of Asian students meeting the benchmark, compared with 46% of white students, 21% of Hispanic students, and 11% of black students.

FIGURE 1-A

ACT-tested 2016 high school graduates meeting ACT college readiness benchmarks in mathematics and science



Source(s)

ACT, 2016. *The Condition of College and Career Readiness 2016*. Iowa City, IA, https://www.act.org/content/dam/act/unsecured/documents/CCCR_National_2016.pdf. Accessed 27 February 2017.

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Other measures of college readiness support the ACT findings. National Association of Educational Progress (NAEP) college-ready indicators provide readiness estimates based on a nationally representative sample of students. The National Assessment Governing Board (NAGB), which sets policy for NAEP, began using NAEP in 2013 to estimate the percentage of grade 12 students who possess the knowledge and skills in reading and mathematics that would make them academically prepared for first-year college coursework. NAGB conducted a decade of research to determine the NAEP scores students need to earn to demonstrate college readiness. According to results from the 2015 NAEP, an estimated 37% of twelfth graders were prepared for college-level coursework in mathematics (Kena et al. 2016), a finding similar to that of ACT and one that is echoed in Achieve Inc.'s 50-state analysis of student performance on college readiness indicators. Achieve found that, even in the highest performing state, only 42% of students were ready for college-level work in mathematics (Achieve Inc. 2016).

[*] Students who meet the mathematics or science benchmark on the ACT have approximately a 75% chance of earning a C or better in the credit-bearing college-level mathematics or science courses most commonly taken by college students (e.g., college algebra and biology).

High School Completers Planning to Pursue a STEM Major in College

With the goals of maintaining global competitiveness and enhancing capacity for innovation, U.S. policymakers have called for increasing the number and diversity of students pursuing degrees and careers in STEM fields. Data from HSLS:09 gave insight into the percentage of high school students planning to major in STEM fields in college. Among respondents who reported plans to pursue a bachelor's degree, 32% indicated plans to pursue a STEM major (Appendix Table 1-28). Asian students were the most likely to identify a STEM major, with 53% of bachelor's degree program respondents identifying a STEM major, compared with 32% of white students, 28% of Hispanic students, and 23% of black students. A higher percentage of male (41%) than female (24%) bachelor's degree program respondents identified a STEM major.

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[1] To calculate the ACGR, states identify the "cohort" of first-time ninth graders in a particular school year and adjust this number by adding any students who transfer into the cohort after ninth grade and subtracting any students who transfer out, emigrate to another country, or die. The ACGR is the percentage of the students in this cohort who graduate with a high school diploma within 4 years. The AFGR uses aggregate student enrollment data to estimate the size of an incoming freshman class, which is the sum of eighth grade enrollment in the first year, ninth grade enrollment for the next year, and tenth grade enrollment for the year after, and then dividing by three. The AFGR is the number of high school diplomas awarded 4 years later divided by the estimated incoming freshman class size.

[2] The earlier editions of *Science and Engineering Indicators* reported U.S. high school graduation rates based on AFGR because the student-level records needed to calculate the ACGR were not available at a state level until recent years.

[3] See https://nces.ed.gov/pubs2016/2016117rev.pdf for a definition of *economically disadvantaged*.

[4] Upper secondary education, as defined by the OECD, corresponds to high school education in the United States. In calculating the U.S. graduation rates, the OECD included only students who earned a regular diploma and excluded those who completed a GED certificate program or other alternative forms of upper secondary education. The OECD defines the typical graduation age as the age of the students at the beginning of the school year: when they graduate at the end of the school year, students will generally be 1 year older than the age indicated. According to the OECD, the typical graduation age in the United States is 17 years old. The U.S. high school graduation rates calculated by the OECD cannot be directly compared with U.S. on-time graduation rates because of the different population bases and calculation methods for the two measures.

[5] International comparisons are often difficult because of differences among education systems, types of degrees awarded across countries, and definitions used in different countries. Some researchers have pinpointed various problems and limitations of international comparisons and warned readers to interpret data, including those published by the OECD, with caution (Adelman 2008; Wellman 2007).

Conclusion

Raising overall student achievement, reducing performance gaps among different groups, increasing advanced coursetaking, recruiting more STEM teachers, and improving college readiness in mathematics and science are high priorities for education reform across the United States. How well does this country perform in these areas? The indicators in this chapter present a mixed picture of the status and progress of elementary and secondary mathematics and science education in the United States. Table 1-26 provides an overall summary of the data presented in this chapter. It shows that despite efforts at reform, there are substantial disparities in STEM performance and opportunity based on students' race or ethnicity and SES. Some disparities persist between male and female students, though the differences are small relative to the disparities by race or ethnicity and SES. In the international arena, the United States performs in the middle of the pack among developed countries on the TIMSS assessments but at the bottom on PISA. Table 1-27 shows that U.S. performance overall in STEM has mostly improved over the long term, though short-term trends show some plateaus and downturns. Following is a summary of the chapter findings by major indicators.

TABLE 1-26

Chapter summary of U.S. performance on K–12 STEM indicators

(Score, percentile, and gaps between groups)

Data year	Assessment	Scale	Average score or percentage	10th percentile	90th percentile	Point range 10th to 90th	Gaps between										
							High and low SES[a]			White and black and Hispanic[b]					Male and female		
							High	Low	Gap	White	Black	Gap	Hispanic	Gap	Male	Female	Gap
2015	NAEP Mathematics Grade 4	0 to 500	240	202	277	75	253	229	24	248	224	24	230	18	241	239	2
2015	NAEP Mathematics Grade 8	0 to 500	282	235	329	94	296	268	28	292	260	32	270	22	282	282	0
2015	NAEP Mathematics Grade 12	0 to 300	152	107	196	89	160	137	23	160	130	30	139	21	153	150	3
2015	NAEP Science Grade 4	0 to 300	154	108	196	88	169	140	29	166	133	33	139	27	154	154	0
2015	NAEP Science Grade 8	0 to 300	154	109	195	86	167	140	27	166	132	34	140	26	155	152	3
2015	NAEP Science Grade 12	0 to 300	150	103	196	93	160	134	26	160	125	35	136	24	153	148	5
2014	NAEP TEL Grade 8	0 to 300	150	104	193	89	163	135	28	160	128	32	138	22	149	151	2
2014	ECLS-K:2011 Mathematics Grade 3	0 to 135	99	NA	NA	NA	103	93	10	103	90	13	94	9	101	97	4
2014	ECLS-K:2011 Science Grade 3	0 to 87	56	NA	NA	NA	59	51	8	59	50	9	52	7	56	55	1
2015	TIMSS Mathematics Grade 4	0 to 1,000	535	432	640	208	600	499	101	541	462	79	492	49	543	536	7
2015	TIMSS Mathematics Grade 8	0 to 1,000	518	408	624	216	573	477	96	559	495	64	515	44	519	517	2
2015	TIMSS Science Grade 4	0 to 1,000	546	439	644	205	603	502	101	570	501	69	518	52	548	544	4
2015	TIMSS Science Grade 8	0 to 1,000	530	421	631	210	579	489	90	557	469	88	502	55	533	527	6
2015	TIMSS Advanced Mathematics	0 to 1,000	485	352	608	256	534	425	109	495	400	95	440	55	500	470	30

Data year	Assessment	Scale	Average score or percentage	10th percentile	90th percentile	Point range 10th to 90th	Gaps between										
							High and low SES[a]			White and black and Hispanic[b]					Male and female		
							High	Low	Gap	White	Black	Gap	Hispanic	Gap	Male	Female	Gap
2015	TIMSS Advanced Physics	0 to 1,000	437	283	589	306	506	363	143	463	334	129	390	73	455	409	46
2015	PISA Mathematics (age 15)	0 to 1,000	470	355	585	230	517	431	86	499	419	80	446	53	474	465	9
2015	PISA Science (age 15)	0 to 1,000	496	368	626	258	546	457	89	531	433	98	470	61	500	493	7
Highest course enrollment[c] (%)																	
2013	Calculus or higher	na	19	na	na	na	37	9	28	22	9	13	15	7	19	19	0
2013	AP/ IB or advanced science	na	21	na	na	na	38	11	27	23	14	9	16	7	20	23	3
Transition to postsecondary (%)																	
2015	On-time high school graduation[d]	na	83	na	na	na	NA	NA	NA	88	75	13	78	10	NA	NA	NA
2015	Immediate college enrollment[e]	na	69	na	na	na	83	69	14	70	63	7	67	2	66	73	7
2016	College ready in mathematics[f]	na	41	na	na	na	NA	NA	NA	50	13	37	27	23	NA	NA	NA
2016	College ready in science	na	36	na	na	na	NA	NA	NA	46	11	35	21	25	NA	NA	NA

NA = not available; na = not applicable.

AP = Advanced Placement/International Baccalaureate; ECLS-K:2011 = Early Childhood Longitudinal Study, Kindergarten Class of 2010–11 (see Appendix Table 1-14 and Appendix Table 1-15); NAEP = National Assessment of Educational Progress (see Appendix Table 1-1 and Appendix Table 1-3); NAEP TEL = National Assessment of Educational Progress, technology and engineering literacy (see Appendix Table 1-5); PISA = Program for International Student Assessment (see Table 1-11); SES = socioeconomic status; STEM = science, technology, engineering, and mathematics; TIMSS = Trends in International Mathematics and Science Study (see Table 1-6 and Table 1-8).

[a] SES is a composite variable derived from parental education level, parental occupation, and family income.

[b] Hispanic may be any race. Black and white refer to individuals who are not of Hispanic origin.

[c] Highest mathematics and science course enrollment of high school completers from High School Longitudinal Study of 2009. See Appendix Tables 1-23 and 1-25.

[d] See Table 1-23.

[e] See Appendix Table 1-27.

[f] See Figure 1-9.

Note(s)

Scales are different for each assessment and are not comparable across grades or assessments. Please use caution when interpreting results.

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TABLE 1-27

Summary of long- and short-term trends in U.S. performance on K–12 STEM indicators

(Trend)

Assessment	Long-term trend		Short-term trend	
	Date span	Trend	Date span	Trend
NAEP Mathematics Grade 4	1990–2015	^	2013–15	v
NAEP Mathematics Grade 8	1990–2015	^	2013–15	v
NAEP Mathematics Grade 12	2005–15	≈	2013–15	v
NAEP Science Grade 4	2009–15	^	na	na
NAEP Science Grade 8	2009–15	^	2011–15	^
NAEP Science Grade 12	2009–12	≈	na	na
TIMSS Mathematics Grade 4	1995–2015	^	2011–15	≈
TIMSS Mathematics Grade 8	1995–2015	^	2011–15	^
TIMSS Science Grade 4	1995–2015	≈	2011–15	≈
TIMSS Science Grade 8	1995–2015	^	2011–15	≈
TIMSS Advanced Mathematics	1995–2015	≈	na	na
TIMSS Advanced Physics	1995–2015	≈	na	na
PISA Mathematics (age 15)	2003–15	≈	2012–15	v
PISA Science (age 15)	2006–15	≈	2012–15	≈
On-time high school graduation[a]	2011–15	^	2014–15	^
Immediate college enrollment[b]	1990–2014	^	2013–14	^

≈ = indicates no significant change; ^ = upward trend in scores; v = downward trend in scores; na = not applicable because data are available for only two time points, so long term is the only trend.

NAEP = National Assessment of Educational Progress (see Appendix Table 1-1 and Appendix Table 1-3); PISA = Program for International Student Assessment (see Figure 1-5); STEM = science, technology, engineering, and mathematics; TIMSS = Trends in International Mathematics and Science Study (see Figure 1-3 and Figure 1-4).

[a] See Table 1-23.

[b] See Appendix Table 1-27.

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NAEP mathematics assessment results show that average mathematics scores for fourth, eighth, and twelfth graders remained relatively flat over the past decade and then declined slightly from 2013 to 2015. These declines are the first since 1990 for fourth and eighth graders and since 2005 for twelfth graders. NAEP science results for fourth and eighth graders were more encouraging, with increases of 4 points in average scores since 2009, although average scores for twelfth graders did not change during the same period. NAEP data indicate that achievement gaps persisted in the United States: low-SES, black, and Hispanic students trailed their peers by large margins, and male students slightly outperformed female students on most NAEP exams. Data from ECLS-K:2011 showed patterns similar to those from NAEP with respect to performance by different subgroups: high-SES students outscored low-SES students, Asian and white students outscored black and Hispanic students, and male students slightly outscored female students. Gaps that were evident between disadvantaged and advantaged groups in kindergarten and first grade remained through the end of third grade.

In the international arena, the nation's fourth graders scored in the top quarter of all participating education systems in mathematics and science on the 2015 TIMSS assessments, although their scores in either subject did not improve since the last administration in 2011. U.S. eighth graders also performed in the top quarter of participating education systems in 2015 and improved in mathematics but not in science since 2011. U.S. 15-year-olds' performance on PISA in 2015 declined in mathematics and did not change significantly in science when compared with the last administration in 2012. The United States scored lower than 36 education systems in mathematics and 18 in science.

Efforts to improve student achievement include raising high school graduation requirements and increasing advanced coursetaking. These efforts are meeting with some success. Most high school completers are taking mathematics courses through at least algebra 2 and science courses through chemistry by the time they finish high school. The number of students taking mathematics and science AP exams continues to grow, with the number of students taking at least one of these exams nearly doubling in the past decade. Despite these gains, significant demographic gaps persist. Black and Hispanic students and students from disadvantaged economic backgrounds take fewer advanced courses and are more likely to attend schools that do not offer advanced courses. Although male and female students have reached parity in many areas, female students lag behind their male counterparts in taking advanced courses in specific fields of science such as AP physics.

Attracting and retaining high-quality STEM teachers continues to be a focus of educators and policymakers, as evidenced by the inclusion in ESSA of multiple provisions related to STEM teachers. The law allows states to use differential pay to attract STEM teachers and provides grants to create STEM master teacher corps, among other incentives. A recent international analysis suggests that the United States ranks low among developed countries with respect to the ratio of teachers' salaries to the salaries of other educated workers, which may play a role in STEM teacher recruitment and retention.

Recent federal and state policies encourage greater use of technology throughout the education system to improve students' learning experiences. The use of instructional technology in K−12 classrooms has been growing rapidly. Many school districts have invested in technology such as computers and mobile devices, and more than two-thirds of school district technology administrators indicated that all the schools in their system fully met Internet bandwidth recommendations for public schools in 2016. Rigorous research on the effects of instructional technology and online learning shows some modest positive effects on student mathematics learning, but more research is needed to determine which technologies are effective and under what conditions.

Ensuring that students graduate from high school and are ready for college or the labor market is an important goal of high school education in the United States. U.S. on-time high school graduation rates have shown steady improvement, reaching 83% by 2015. In the broad international context, the United States ranked 19th in graduation rates among 25 OECD countries with available data in 2014. The vast majority of high school seniors expect to attend college after completing high school, and many do so directly after high school graduation. Achievement data suggest, however, that the majority of college-bound students are not academically prepared for success in mathematics and science coursework at the college level.

Glossary

Definitions

Advanced Placement (AP): Courses that teach college-level material and skills to high school students who can earn college credits by demonstrating advanced proficiency on a final course exam. The College Board develops curricula and exams for AP courses, available for a wide range of academic subjects.

Blended learning: Any time a student learns at least in part at a supervised, traditional school location away from home and at least in part through online delivery with some element of student control over time, place, path, and/or pace; often used synonymously with "hybrid learning."

Distance education: A mode of delivering education and instruction to students who are not physically present in a traditional setting such as a classroom. Also known as "distance learning," it provides access to learning when the source of information and the learners are separated by time and/or distance.

Elementary school: A school that has no grades higher than 8.

Eligibility for National School Lunch Program: Student eligibility for this program, which provides free or reduced-price lunches, is a commonly used indicator of family poverty. Eligibility information is part of the administrative data schools keep and is based on parent-reported family income and family size.

English language learner: An individual who, because of any of the following reasons, has sufficient difficulty speaking, reading, writing, or understanding the English language to be denied the opportunity to learn successfully in classrooms where the language of instruction is English or to participate fully in the larger U.S. society. Such an individual (1) was not born in the United States or has a native language other than English, (2) comes from environments where a language other than English is dominant, or (3) is an American Indian or Alaska Native and comes from an environment where a language other than English has had a significant effect on the individual's level of English language proficiency.

GED certificate: This award is received after successfully completing the General Educational Development (GED) test. The GED program, sponsored by the American Council on Education, enables individuals to demonstrate that they have acquired a level of learning comparable with that of high school graduates.

High school: A school that has at least one grade higher than 8 and no grade in K–6.

High school completer: An individual who has been awarded a high school diploma or an equivalent credential, including a GED certificate.

High school diploma: A formal document regulated by the state certifying the successful completion of a prescribed secondary school program of studies. In some states or communities, high school diplomas are differentiated by type, such as an academic diploma, a general diploma, or a vocational diploma.

Middle school: A school that has any of grades 5–8, no grade lower than 5, and no grade higher than 8.

Online learning: Education in which instruction and content are delivered primarily over the Internet.

Organisation for Economic Co-operation and Development (OECD): An international organization of 34 countries headquartered in Paris, France. The member countries are Australia, Austria, Belgium, Canada, Chile, Czech Republic, Estonia, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, South Korea, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom, and United States. Among its many activities, the OECD compiles social, economic, and science and technology statistics for all member and selected nonmember countries.

Postsecondary education: The provision of a formal instructional program with a curriculum designed primarily for students who have completed the requirements for a high school diploma or its equivalent. These programs include those with an academic, vocational, or continuing professional education purpose and exclude vocational and adult basic education programs.

Remedial courses: Courses taught within postsecondary education that cover content below the college level.

Repeating cross-sectional studies: This type of research focuses on how a specific group of students performs in a particular year, then looks at the performance of a similar group of students at a later point. An example would be comparing fourth graders in 1990 with fourth graders in 2011 in NAEP.

Scale score: Scale scores place students on a continuous achievement scale based on their overall performance on the assessment. Each assessment program develops its own scales.

Key to Acronyms and Abbreviations

ACGR: adjusted cohort graduation rate

AFGR: averaged freshman graduation rate

AP: Advanced Placement

CRDC: Civil Rights Data Collection

CREDO: Center for Research on Education Outcomes

ECLS-K: Early Childhood Longitudinal Study-Kindergarten

ESSA: Every Student Succeeds Act

GED: General Educational Development

HSLS: High School Longitudinal Study

IB: International Baccalaureate

IEA: International Association for the Evaluation of Educational Achievement

K–12: kindergarten through 12th grade

NAEP: National Assessment of Educational Progress

NAGB: National Assessment Governing Board

NCES: National Center for Education Statistics

NRC: National Research Council

NSF: National Science Foundation

NSLP: National School Lunch Program

NTPS: National Teacher and Principal Survey

OECD: Organisation for Economic Co-operation and Development

PISA: Program for International Student Assessment

SASS: Schools and Staffing Survey

SES: socioeconomic status

STEM: science, technology, engineering, and mathematics

TEL: technology and engineering literacy

TIMSS: Trends in International Mathematics and Science Study

UK: United Kingdom

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CHAPTER 2

Higher Education in Science and Engineering

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Highlights

Characteristics of the U.S. Higher Education System

A disproportionate number of S&E bachelor's, master's, and doctorate degree holders graduate from a small number of universities with very high levels of research activity. But other types of institutions are making substantial contributions to educating the nation's S&E graduates. In 2015:

- Institutions with very high research activity awarded 72% of doctoral degrees, 42% of master's degrees, and 37% of bachelor's degrees in S&E fields.
- Master's-level colleges and universities awarded 28% of S&E bachelor's degrees and 25% of S&E master's degrees; 4-year colleges supplied the rest.
- Minority-serving institutions play an important role in underrepresented minorities' educational and career pathways. About 30% of Hispanic S&E doctorate recipients who earned their doctorates between 2011 and 2015 had obtained their baccalaureate credential at a high-Hispanic-enrollment institution, and 24% of black S&E doctorate recipients who received their doctorates in the same period had obtained their baccalaureate degree at a historically black college or university.
- Nearly one in five U.S. citizens or permanent residents who received an S&E doctoral degree from 2011 to 2015 had earned some college credit from a community or 2-year college.

Higher education spending and revenue patterns and trends continue to undergo substantial changes with a higher share of total costs borne by students and parents.

- Between 2000 and 2015, average revenue per full-time equivalent (FTE) student from net tuition at public very high research universities nearly doubled, whereas state and local appropriations fell by 34%.
- Although tuition remained lower at public very high research universities than at their private counterparts, average revenue from student tuition increased more rapidly at public institutions.
- In public very high research universities, revenues from federal appropriations, grants, and contracts per FTE student grew by 11% between 2000 and 2015, and research expenditures per FTE student grew by the same percentage (11%). In private very high research universities, revenues from federal appropriations, grants, and contracts per FTE student grew by 14%, and research expenditures per FTE student increased by 25%.
- Between 2008 and 2010, during a period largely coinciding with the economic recession, expanding enrollment in community colleges, coupled with reductions in state and local appropriations, contributed to a 9% reduction in instructional spending per FTE student. Instructional spending per FTE student continued to decline in 2011 but increased by 14% between 2012 and 2015, while enrollment declined as the U.S. economy improved.

Between 2006–07 and 2016–17, estimated average net tuition and fees paid by full-time undergraduate students in public 4-year colleges increased by about 30% after adjusting for inflation.

- With rising tuition, students rely on financial aid and loans to fund their education. Undergraduate debt varies by type of institution and state. Overall, it does not vary much by field of study.
- Levels of debt among doctorate recipients vary by field. In S&E fields, high levels of graduate debt were most common among doctorate recipients in social sciences, psychology, and medical and other health sciences.

- At the time of doctoral degree conferral, 43% of 2015 S&E doctorate recipients had debt related to their undergraduate or graduate education.

Undergraduate Education, Enrollment, and Degrees

Undergraduate enrollment in U.S. higher education rose from 13.3 million in 2000 to 17.3 million in 2015. The largest increases occurred in 2000–02 and 2008–10 and thus coincided with the two economic downturns, continuing a well-established pattern seen in earlier economic downturns. Enrollment peaked at 18.3 million in 2010 but has since declined.

- Associate's colleges enroll the largest number of students, followed by master's colleges and universities and doctorate-granting institutions with very high research activity.
- Increased enrollment in higher education is projected to come mainly from minority groups, particularly Hispanics.

The number of S&E associate's degrees increased from 38,000 to 91,000 between 2000 and 2015. During this period, the growth of S&E degrees at the associate's level (136%) was higher than growth at the bachelor's (63%), master's (88%), and doctoral levels (60%).

- In 2015, about 9% of the associate's degrees awarded were in S&E, and another 14% were awarded in S&E technologies.
- Since 2000, the number of associate's degrees in S&E technologies, which have a more applied focus, grew by 72%, to 144,000. Nearly three-quarters of these associate's degrees are in health technologies, and close to one-quarter are in engineering technologies.

The number of S&E bachelor's degrees has risen steadily in the United States over the past 15 years, peaking at more than 650,000 in 2015. S&E degrees continued to account for about one-third of all bachelor's degree awards during this period.

- All S&E fields experienced increases in the numbers of bachelor's degrees awarded in 2015, including computer sciences, which had declined sharply in the mid-2000s and had remained flat through 2009.
- Women have earned about 57% of all bachelor's degrees and about half of all S&E bachelor's degrees since the late 1990s. Men earn the majority of bachelor's degrees in engineering, computer sciences, mathematics and statistics, and physics, and women earn the majority in the biological, agricultural, and social sciences and in psychology.

The racial and ethnic composition of those earning S&E bachelor's degrees is changing, reflecting population changes and increases in college attendance among members of minority groups.

- For all racial and ethnic groups, the total number of bachelor's degrees earned, the number of S&E bachelor's degrees earned, and the number of bachelor's degrees in most broad S&E fields have increased since 2000.
- Between 2000 and 2015, the share of bachelor's degrees awarded to Hispanics among U.S. citizens and permanent residents increased from 7% to 13%, in S&E and in all fields combined, and remained steady at about 1% for American Indians and Alaska Natives. In the same period, the share of bachelor's degrees awarded to blacks remained stable at 9% in S&E fields but increased from 9% to 10% in all fields.

The number of international undergraduate student enrollment in U.S. academic institutions increased consistently between fall 2012 and fall 2016 but fell 2% between fall 2016 and fall 2017.

- The decline in international undergraduate enrollment between 2016 and 2017 is due solely to a decline in enrollment in non-S&E fields—enrollment in S&E fields held steady over this time.
- In the most recent academic year, the number of international visa holders increased in computer sciences and mathematics (by 11% and 5% respectively) but declined in engineering (5%), social sciences (3%), and non-S&E fields (4%).
- In fall 2017, China, Saudi Arabia, India, South Korea, and Kuwait were the top countries sending S&E undergraduates to the United States, as in the previous year. Compared to fall 2016, the number of undergraduates from China, India, and Kuwait enrolled in fall 2017 declined (by 3%, 11%, and 4% respectively) while the number from Saudi Arabia and South Korea declined (by 18% and 7% respectively).

Among students who began postsecondary education in 4-year colleges and universities in 2011–12, about 76% were still enrolled 3 years later, either at their first institution or at another and 6% had earned either an associate's or a bachelor's degree.

- Among students in 4-year institutions, those who had declared an S&E major were more likely to be enrolled 3 years later than those who had declared a non-S&E major.
- Among students in 2-year institutions, the level of degree attainment or continued enrollment did not vary much by the broad field of major that beginning students had declared in their first year of postsecondary study. However, students who had been undecided about their major early on were more likely than other students to have dropped out 3 years later.

Graduate Education, Enrollment, and Degrees

Graduate enrollment in S&E increased from about 493,000 to almost 668,000 between 2000 and 2015.

- Graduate enrollment grew in most S&E fields, with particularly strong growth in computer sciences, mathematics and statistics, medical sciences, and engineering.
- Since 2008, enrollment of international students in S&E fields has been rising, while graduate enrollment of U.S. citizens and permanent residents has declined overall. In 2015, international students accounted for 36% of S&E graduate students, compared with 26% in 2008.

In 2015, the federal government was the primary source of financial support for 15% of full-time S&E graduate students, the lowest proportion since at least 2000.

- The recent decline in the share of S&E graduate students who rely primarily on federal financial support was especially pronounced in the biological sciences (from 36% in 2000 to 26% in 2015), the physical sciences (from 35% in 2000 to 27% in 2015), and the medical sciences (from 22% in 2000 to 9% in 2015).
- In 2015, the federal government funded 55% of S&E graduate students who were primarily supported with traineeships, 45% of those with research assistantships, and 22% of those with fellowships.
- Graduate students in the biological sciences, the physical sciences, and engineering received relatively more federal financial support than those in computer sciences, mathematics and statistics, medical and other health sciences, psychology, and social sciences.

The number of international graduate students in U.S. academic institutions had increased consistently between fall 2012 and fall 2016 but declined by 6% in S&E fields and by 5% in non-S&E fields by fall 2017.

- Between fall 2016 and fall 2017, the number of international graduate students enrolled in S&E fields declined in computer sciences and engineering, increased in mathematics, and remained stable in other S&E fields.
- A larger proportion of international graduate students than international undergraduate students enrolled in S&E. More than 6 in 10 international graduate students in the United States in fall 2017 were enrolled in S&E fields, compared with about 4 in 10 international undergraduates.
- In fall 2017, 69% of the international S&E graduate students in the United States came from China and India, similar to prior years.

Master's degrees awarded in S&E fields increased from about 96,000 in 2000 to more than 180,000 in 2015.

- The number of master's degrees awarded in engineering in 2015 was the highest in the last 16 years. The number of master's degrees in computer sciences awarded in 2015 surpassed its peak in 2004.
- Increases occurred in most major S&E fields, with the largest in mathematics and statistics, biological sciences, computer sciences, and engineering.
- The number and percentage of master's degrees awarded to women in most major S&E fields have increased since 2000.
- The number of S&E master's degrees awarded increased for all racial and ethnic groups from 2000 to 2015. While the proportion of degrees earned by blacks and Hispanics increased, that of American Indians or Alaska Natives remained flat, and those of whites and Asians and Pacific Islanders declined.

In 2015, U.S. academic institutions awarded about 45,000 S&E doctorates, up from nearly 28,000 in 2000.

- The number of S&E doctorates conferred annually by U.S. universities increased among U.S. citizens and permanent residents and among temporary visa holders.
- Among fields that award large numbers of doctorates, the largest increases in degrees awarded between 2000 and 2015 were in engineering and in computer sciences.

Students on temporary visas continue to earn high proportions of U.S. S&E doctorates, including the majority of degrees in some fields. They also earned large shares of the master's degrees in S&E fields. In contrast, they earn smaller shares of undergraduate S&E degrees.

- In 2015, international students earned more than half of the doctoral degrees awarded in engineering, economics, computer sciences, and mathematics and statistics. Their overall share of S&E degrees was 34%.
- The number of temporary visa holders earning S&E doctoral degrees grew consistently between 2011 and 2014 but remained flat in 2015.
- Students on temporary visas earned 2% of the associate's and 5% of the bachelor's degree in S&E fields in 2015.

International S&E Higher Education

In 2014, more than 7.5 million first university degrees, broadly equivalent to a bachelor's degree, were awarded in S&E worldwide. Students in India earned about 25% of those degrees, those in China earned about 22%, those in the European Union earned about 12%, and those in the United States earned about 10%.

- S&E degrees continue to account for about one-third of all bachelor's degrees awarded in the United States. In Japan, more than half of the first university degrees were awarded in S&E fields in 2014; in China, nearly half.
- In the United States, about 6% of all bachelor's degrees awarded in 2014 were in engineering. This compares with about 18% throughout Asia and 33% in China.

In 2014, the United States awarded the largest number of S&E doctoral degrees of any individual country, followed by China, Russia, Germany, the United Kingdom, and India.

- The numbers of S&E doctoral degrees awarded in China and the United States have risen substantially in recent years. S&E doctorates awarded in South Korea and in many European countries have risen more modestly. S&E doctorates awarded in Japan increased fairly steadily through 2006 but have declined since then.
- As a result of large government investments in higher education, in 2007 China overtook the United States as the world leader in the number of doctoral degrees awarded in the natural sciences and engineering (which includes agricultural, biological, and physical sciences, mathematics and statistics, and computer sciences and excludes social and behavioral sciences). Since 2010, this number in China has risen more slowly.

International student mobility expanded over the past two decades as countries increasingly compete for international students.

- The United States remains the destination for the largest number of internationally mobile undergraduate and graduate students worldwide, although its share decreased from 25% in 2000 to 19% in 2014.
- Other top destinations for international students include the United Kingdom, Australia, France, and Germany.

Introduction

Chapter Overview

This chapter focuses on the development of human capital in S&E through higher education. Postsecondary education provides the advanced skills needed for an educated citizenry, a competitive workforce, and—in the case of graduate-level S&E education—the research capability necessary for innovation.

Indicators presented in this chapter are discussed in the context of national and global developments, including changing demographics, increasing international student mobility, and increasing global competition in higher education. The composition of the U.S. college-age population is becoming more diverse as the Asian and Hispanic shares of the population increase. During the latest economic downturn, public institutions of higher education faced unique pressures from a combination of increasing enrollments and tight state budgets. Private institutions likewise experienced financial challenges stemming from declining incomes and the effects of stock market fluctuations on endowment growth. Technology has enabled rapid growth in the delivery of online courses; the consequences of these changes are not well understood.

Over the past decade and a half, governments around the globe have increasingly regarded higher education as an essential national resource. Although the United States has historically been a world leader in providing broad access to higher education and in attracting international students, many other countries are providing expanded educational access to their own populations and are attracting growing numbers of international students. Nevertheless, in recent years, increases in international students contributed to most of the growth in overall S&E graduate enrollment in the United States. After a decline in the number of international students coming to the United States after 11 September 2001, international student enrollment in S&E had recovered, but in the last year their numbers have dropped once again.

Chapter Organization

This chapter begins with an overview of the characteristics of U.S. higher education institutions that provide instruction in S&E, followed by a discussion of characteristics of U.S. undergraduate and graduate education.[1] Trends are discussed by field and demographic group, with attention to the flow of international students into the United States by country of origin. Various international higher education indicators include comparative S&E degree production in several world regions and measures of the growing dependence of industrialized countries on international S&E students.

The chapter draws on a variety of federal and nonfederal sources, primarily surveys conducted by the National Center for Science and Engineering (NCSES) within the National Science Foundation (NSF) and by the National Center for Education Statistics (NCES) at the Department of Education. International data come from the Organisation for Economic Co-operation and Development (OECD); the United Nations Educational, Scientific and Cultural Organization (UNESCO) Institute for Statistics (UIS); and individual country sources. Most of the data in this chapter are from censuses of the relevant population—for example, all students receiving degrees from U.S. academic institutions—and are not subject to sampling variability.

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[1] For data on postdoctoral scientists and engineers see Chapter 3 and Chapter 5. For data on stay rates of doctorate recipients see Chapter 3.

The U.S. Higher Education System

This section discusses the characteristics of U.S. higher education institutions that provide S&E education and various aspects of and trends in their finances.

Institutions Providing S&E Education

The U.S. higher education system consists of many diverse academic institutions that vary in their missions, learning environments, selectivity levels, religious affiliations, types of students served, types of degrees offered, sectors (public, private nonprofit, or private for-profit), and costs (Kena et al. 2016). During the 2015–16 academic year, there were approximately 4,600 postsecondary degree-granting institutions in the United States; about two-thirds (66%) of these offered 4-year or higher degrees, and the remainder offered 2-year degrees (Table 2-1). More than half of the 4-year institutions are private nonprofit, 24% are public, and 23% are private for-profit. Most 2-year institutions are public (58%), but a large proportion (36%) are private for-profit (Table 2-1).

TABLE 2-1

Degree-granting institutions, by control and level of institution: 2015–16

(Number)

Highest degree awarded	All degree-granting institutions	Public	Private nonprofit	Private for-profit
Total	4,583	1,620	1,701	1,262
2-year	1,579	910	107	562
4-year	3,004	710	1,594	700

Source(s)

National Center for Education Statistics, Integrated Postsecondary Education Data System (IPEDS), Institutional Characteristics component, 2015–16.

Science and Engineering Indicators 2018

In 2015, U.S. academic institutions awarded nearly 3.8 million associate's, bachelor's, master's, and doctoral degrees, 25% of them in S&E fields (Appendix Table 2-1).[1] Public institutions produced the bulk of S&E and non-S&E degrees (Table 2-2). For example, public institutions awarded nearly 70% of S&E bachelor's and doctoral degrees and 55% of S&E master's degrees.

Although relatively few (97), doctorate-granting institutions with very high research activity—public and private—are the leading producers of S&E degrees: these research institutions awarded 72% of doctoral degrees, 42% of master's degrees, and 37% of bachelor's degrees in S&E fields in 2015 (Appendix Table 2-1) (see sidebar Carnegie Classification of Academic Institutions). Master's colleges and universities awarded another 28% of S&E bachelor's degrees and 25% of S&E master's degrees in 2015.

TABLE 2-2

Degree awards, by degree level and institutional control: 2015

(Number)

Degree awards	Total	Public	Private nonprofit	Private for-profit
All fields	3,772,587	2,436,359	988,737	347,491
Associate's	1,024,186	824,380	62,461	137,345
Bachelor's	1,915,608	1,216,648	565,271	133,689
Master's	763,678	351,798	340,130	71,750
Doctorate	69,115	43,533	20,875	4,707
S&E	960,594	642,527	268,156	49,911
Associate's	90,589	71,107	3,125	16,357
Bachelor's	649,922	444,621	182,088	23,213
Master's	180,905	100,090	71,748	9,067
Doctorate	39,178	26,709	11,195	1,274

Source(s)

National Center for Education Statistics, Integrated Postsecondary Education Data System (IPEDS), Completions Survey; National Science Foundation, National Center for Science and Engineering Statistics, WebCASPAR database, https://ncsesdata.nsf.gov/webcaspar/.

Science and Engineering Indicators 2018

SIDEBAR

Carnegie Classification of Academic Institutions

The Carnegie Classification of Institutions of Higher Education is widely used in higher education research to characterize and control for differences in academic institutions.

The 2010 classification update retains the structure adopted in 2005 and classified about 4,200 institutions. More than three-quarters of the institutions added in that update (77%) were from the private for-profit sector, 19% were from the private nonprofit sector, and 4% were from the public sector.

The Carnegie classification categorizes academic institutions primarily on the basis of highest degree conferred, level of degree production, and research activity.* In this report, several Carnegie categories have been aggregated for statistical purposes. The characteristics of those aggregated groups are as follows:

- *Doctorate-granting universities* include institutions that award at least 20 doctoral degrees per year. They include three subgroups based on level of research activity: very high research activity (97 institutions), high research activity (103 institutions), and doctoral/research universities (82 institutions). Because doctorate-granting institutions with very high research activity are central to S&E education and research, data on these institutions are reported separately.
- *Master's colleges and universities* include the 652 institutions that award at least 50 master's degrees and fewer than 20 doctoral degrees per year.
- *Baccalaureate colleges* include the 749 institutions at which baccalaureate degrees represent at least 10% of all undergraduate degrees and that award fewer than 50 master's degrees or 20 doctoral degrees per year.
- *Associate's colleges* include the 1,692 institutions at which all degrees awarded are associate's degrees or at which bachelor's degrees account for less than 10% of all undergraduate degrees.
- *Special-focus institutions* are the 744 institutions at which at least 75% of degrees are concentrated in a single field or a set of related fields (e.g., medical schools and medical centers, schools of engineering, schools of business and management).
- *Tribal colleges* are the 33 colleges and universities that are members of the American Indian Higher Education Consortium.

* Research activity is based on two indexes (aggregate level of research and per capita research activity) derived from a principal components analysis of data on research and development expenditures, S&E research staff, and field of doctoral degree. See http://carnegieclassifications.iu.edu/ for more information on the classification system and on the methodology used in defining the categories.

Baccalaureate colleges were the source of relatively few S&E bachelor's degrees (11%) (Appendix Table 2-1), but they produce 13% of future S&E doctorate recipients (NSF/NCSES 2013). When adjusted by the number of bachelor's degrees awarded in all fields, the top 50 baccalaureate colleges as a group yield more future S&E doctorates per 100 bachelor's degrees awarded than all other types of institutions except very high research universities.[2]

Minority-serving Institutions

Minority-serving academic institutions (MSIs) can be defined by legislation or by the proportion of minority student enrollment in them (Li 2007). Examples of MSIs established by legislation include historically black colleges or universities (HBCUs, see sidebar 💬 Historically Black Colleges and Universities) and tribal colleges or universities[3] (TCUs). Given their legal definition, the number of institutions in these groups cannot increase in number unless Congress acts to designate additional institutions in those groups. In contrast, high-Hispanic-enrollment institutions[4] (HHEs, see sidebar 💬 High-Hispanic-Enrollment Institutions: A Typology) are a type of MSI based on the percentage of minority student enrollment. The number of institutions in these groups vary from year to year based on the enrollment of students in their respective minority groups.[5]

MSIs enroll a substantial fraction of underrepresented minority undergraduates (NSF/NCSES 2017a). In 2015, HBCUs awarded 16% of the 54,000 S&E bachelor's degrees earned by black U.S. citizens and permanent residents, and HHEs awarded about 34% of the 79,000 S&E bachelor's degrees earned by Hispanics. The proportion of blacks earning S&E bachelor's degrees from HBCUs has been declining in recent years. The proportion of Hispanics earning S&E bachelor's degrees from HHEs declined through 2011 but has been stable at about 34% since then. Tribal colleges, which mainly offer 2-year degrees, account for about 4% of the nearly 3,000 S&E bachelor's degrees awarded to American Indians; this proportion has increased slightly in the last 5 years.[6]

SIDEBAR

Historically Black Colleges and Universities

The Higher Education Act of 1965, as amended, defines a historically black college or university (HBCU) as “any historically black college or university that was established prior to 1964, whose principal mission was, and is, the education of black Americans.” These institutions were established and developed in an environment of legal segregation and greatly contributed to the progress of blacks by providing access to higher education (Hill, 1985). In 2015–16, there were 102 HBCUs in operation in 19 states, the District of Columbia, and the U.S. Virgin Islands. Half of these institutions were public and half were private nonprofit institutions. The number of students enrolled at HBCUs increased by 32% between 1976 and 2015 to about 293,000. In comparison, the number of students enrolled in degree-granting institutions increased by 84%, to about 20 million during the same period (NCES 2017). In 2015, the majority of HBCU students were enrolled in 4-year institutions (89%) and the remainder were enrolled in 2-year institutions. More than three-quarters of HBCU students attended public institutions (75%) and 25% attended private nonprofit institutions.*

Although HBCUs were originally established to educate black or African American students, they enroll a diverse student body. In 2015, students who were not black or African American were 24% of total enrollment in HBCUs, up from 15% in 1976 (NCES 2017).[†]

* Special tabulation from the 2015 Fall Enrollment survey in https://ncsesdata.nsf.gov/webcaspar/.

[†] Special tabulation from the 2015 Fall Enrollment survey in https://ncsesdata.nsf.gov/webcaspar/.

SIDEBAR

High-Hispanic-Enrollment Institutions: A Typology

The demographic composition of the United States has been changing. According to the latest Census Bureau projections, the proportion of Hispanics between the ages of 20 and 24 is expected to grow from 22% in 2015 to 32% in 2060 (National Science Board 2016). Along these demographic trends, the number of colleges and universities serving large numbers of Hispanic students has increased considerably.

High-Hispanic-enrollment institutions (HHEs) are degree-granting, nonprofit colleges and universities where full-time equivalent undergraduate enrollment is at least 25% Hispanic students.* The number of HHEs has more than doubled from 189 in 1994 to 432 in 2015, accounting now for 13% of all degree-granting public and private nonprofit institutions. In addition, about 300 institutions enroll between 15% and 24% Hispanic students; these institutions are considered “emerging HHEs.” In 2015, HHEs enrolled a total of 3.9 million students; nearly half of them were Hispanic, but more than one-quarter were white, and nearly 1 in 10 was black. About 53% of the students enrolled in an HHE were attending part time.

HHEs are diverse. In 2014, about half of them were 2-year institutions, half of them were 4-year institutions, and most were public.

Núñez, Crisp, and Elizondo (2016) conducted an empirical analysis of HHEs with data from the Integrated Postsecondary Education Data System (IPEDS), the Census Bureau, and the American Community Survey. The study was based on the 2008–09 IPEDS data because the data for that academic year contained the most complete information on HHEs. In 2008–09, the data included 268 accredited HHEs. Using cluster analysis, they classified HHEs into six somewhat homogeneous groups as follows:

1. *Urban enclave community colleges* represented 37% of all HHEs and include public institutions that offer associate’s degrees and certificates as their highest degrees. The institutions in this group enroll large numbers of students, the vast majority of whom are in cities or suburbs, and more than half are in the West. More than two-thirds of the students were enrolled part time, and a similar proportion of the faculty worked part time.

2. *Rural dispersed community colleges* represented 13% of all HHEs. They also include public institutions offering associate’s degrees and certificates as their highest degrees; however, in this case, they were mostly in rural and isolated areas and had lower student enrollment than the community colleges in the first group. About two-thirds of them were in the South, particularly in the Southwest. About 65% of the students were enrolled part time, and 41% of their faculty worked part time.

3. *Big system 4 years* represented 21% of the HHEs and had the highest student enrollment of all the clusters. These institutions tended to be in a state public institution system (e.g., the California State University system, the City University of New York, the University of Texas System). The vast majority offered bachelor’s degrees or higher, and more than three-quarters were public. These institutions provide broad access to students, admitting a higher proportion of students than the other 4-year institutions in the groups below. The majority of students in these institutions were enrolled full time, and more than half of the faculty worked full time.

4. *Small community 4 years* were smaller than the others, representing 9% of HHEs. Nearly all of them were private and offered bachelor’s or higher degrees. They included some small liberal arts institutions and several religious ones. They were mostly in urban and suburban areas with high levels of educational attainment in the West and the

South. Compared with the previous clusters, this group included more selective institutions. This group also employed a lower proportion of Hispanic faculty members. Two-thirds of the students in these institutions were enrolled full time, and only 46% of the faculty worked full time.

5. *Puerto Rican institutions* represented 19% of all HHEs, and the vast majority were in cities and suburbs in Puerto Rico. More than two-thirds of these HHEs were private, and nearly 90% offered bachelor's degrees or higher. Three-quarters of the students are enrolled full time; most of the faculty worked part-time.
6. *Health sciences schools* represented the only two HHEs focused on health sciences, the University of Texas Health Science Center and the University of Puerto Rico Medical School. These institutions had low enrollment, a higher proportion of female students, a higher proportion of full-time students and faculty, and selective admission requirements.

This classification shows the diversity of HHEs in terms of their geographic locations, faculty and student body, and academic programs offered.

* Many researchers use the term "high-Hispanic enrollment" and "Hispanic-serving institution" (HSI) interchangeably. HSIs meet the federally designated criterion (i.e., public and private nonprofit institutions whose undergraduate, full-time equivalent student enrollment is at least 25% Hispanic) and are therefore eligible to apply for Hispanic-serving institution status. Based on the Title V program under the Higher Education Act (also known as the "Developing Hispanic-Serving Institutions Program") these institutions are eligible for federal grants, contracts, or benefits to expand educational opportunities and improve the educational attainment of Hispanic students. Because there is no information on whether institutions apply for the HSI designation, NCSES uses the 25% enrollment criterion to determine which institutions have high-Hispanic enrollment. For additional information, see https://www2.ed.gov/about/offices/list/ope/idues/hsidivision.html, accessed 15 May 2017.

HHEs and HBCUs also play an important role in training Hispanic and black students for doctoral-level study in S&E fields. Of Hispanics who earned an S&E doctorate between 2011 and 2015, nearly 30% had obtained their baccalaureate at an HHE (▦Table 2-3). Similarly, 24% of black S&E doctorate recipients had an HBCU baccalaureate (▦Table 2-4). HBCUs were the second-largest contributor of black S&E doctorate recipients, behind only institutions with very high research activity (NSF/NCSES 2013).

TABLE 2-3

Distribution of U.S. citizen and permanent resident S&E doctorate recipients whose baccalaureate origin is a high-Hispanic-enrollment institution, by ethnicity and race: 2011–15

(Number)

Ethnicity and race	All	Earned baccalaureate degree from a high-Hispanic-enrollment institution		
		Yes	No	Yes (%)
All ethnicities and races	115,369	5,822	109,547	5.0
Hispanic or Latino	7,337	2,151	5,186	29.3
Not Hispanic or Latino				
American Indian or Alaska Native	350	35	315	10.0
Asian	11,545	315	11,230	2.7
Black or African American	6,073	302	5,771	5.0
White	84,277	2,679	81,598	3.2
More than one race	3,024	170	2,854	5.6
Other race or race not reported	895	57	838	6.4
Ethnicity not reported	1,868	113	1,755	6.0

Note(s)

Reporting categories for ethnicity and race were expanded in 2013; comparisons with data before 2013 should be made with caution.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2016), 2015 Survey of Earned Doctorates (SED).

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TABLE 2-4

U.S. citizen and permanent resident S&E doctorate recipients whose baccalaureate origin is an HBCU, by ethnicity and race: 2011–15

(Number)

Ethnicity and race	All	Earned baccalaureate degree from an HBCU		
		Yes	No	Yes (%)
All ethnicities and races	115,369	1,640	113,729	1.4
Hispanic or Latino	7,337	33	7,304	0.4
Not Hispanic or Latino				
American Indian or Alaska Native	350	s	s	s
Asian	11,545	10	11,535	0.1
Black or African American	6,073	1,462	4,611	24.1
White	84,277	70	84,207	0.1
More than one race	3,024	28	2,996	0.9
Other race or race not reported	895	s	s	s
Ethnicity not reported	1,868	29	1,839	1.6

s = suppressed for reasons of confidentiality and/or reliability.

HBCU = historically black college or university.

Note(s)

Reporting categories for ethnicity and race were expanded in 2013; comparisons with data before 2013 should be made with caution.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2016), 2015 Survey of Earned Doctorates (SED).

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Community Colleges

Community colleges (also known as public 2-year colleges or associate's colleges) play a key role in increasing access to higher education for all citizens. These institutions serve diverse groups of students and offer a more affordable means of participating in postsecondary education. Community colleges prepare students to enter the workforce with certificates or associate's degrees or to transition to 4-year colleges or universities, often before receiving a 2-year degree. Community colleges tend to be closely connected with local businesses, community organizations, and government, so they can be more responsive to local workforce needs (Olson and Labov 2012).

In the 2015–16 academic year, there were 910 community colleges in the United States, enrolling 6.2 million students, or nearly one-third of all postsecondary students (NCES 2017). Most (62%) community college students enrolled part time. Responding to the economic recession in the late 2000s, enrollment in community colleges peaked in 2010 at 7.2 million but has declined with improving labor markets (Ginder and Kelly-Reid 2017; Ginder, Kelly-Reid, and Mann 2014; Knapp, Kelly-Reid, and Ginder 2009, 2011).

Community colleges play a significant role in educating students who go on to acquire advanced S&E degrees. About 19% of U.S. citizens and permanent residents with S&E doctoral degrees earned between 2011 and 2015 reported having some college credit from a community or 2-year college (▦ Table 2-5). In fact, 47% of all recent S&E graduates had done some coursework at a community college (in 2003, it was 48%, according to the National Survey of College Graduates).[7] Graduates in the biological and social sciences were more likely than those in the physical and computer sciences and in engineering to have attended a community college.

TABLE 2-5 ▦

U.S. citizen and permanent resident S&E doctorate recipients who reported earning college credit from a community or 2-year college, by ethnicity and race: 2011–15

(Number)

Ethnicity and race	All	Earned college credit from a community or 2-year college		
		Yes	No	Yes (%)
All ethnicities and races	113,942	21,185	92,757	18.6
Hispanic or Latino	7,142	1,640	5,502	23.0
Not Hispanic or Latino				
American Indian or Alaska Native	335	117	218	34.9
Asian	11,671	1,498	10,173	12.8
Black or African American	6,067	1,132	4,935	18.7
White	83,965	15,785	68,180	18.8
More than one race	3,035	657	2,378	21.6
Other race or race not reported	857	191	666	22.3
Ethnicity not reported	870	165	705	19.0

Note(s)

Includes only respondents to the community college question. Reporting categories for ethnicity and race were expanded in 2013; comparisons with data before 2013 should be made with caution.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2016), 2015 Survey of Earned Doctorates (SED).

Science and Engineering Indicators 2018

Female S&E bachelor's and master's degree recipients were more likely than males to have attended a community college (▦Table 2-6). Attendance levels as measured by the proportion who took courses at a community college were highest among U.S. citizens, followed by permanent visa holders, and were much lower among temporary visa holders. Among racial and ethnic groups, attendance levels were highest among Hispanics and lowest among Asians. Attendance fell with rising parental education level, illustrating the special access function of these institutions.

Recent S&E graduates (1.3 million) who took courses in community colleges (nearly 600,000) report doing so at different points in their educational careers. Nearly half of them reported doing so after high school but before enrolling in a 4-year college or university or while enrolled in college but before receiving a bachelor's degree. About one in three used a community college as a bridge between high school and college enrollment. One in five attended a community college after receiving their first bachelor's degree. One in 10 reported taking courses at a community college after leaving a 4-year college without receiving their first bachelor's degree.[8]

Recent S&E graduates took courses at community colleges for various reasons. The most prevalent reason was to earn credits toward a bachelor's degree (30%), followed by preparation for college to increase the chance of acceptance at a 4-year institution (17%), for financial reasons (14%), and to earn college credits while still attending high school (13%). Other reasons mentioned included to complete an associate's degree (6%); to gain further skills or knowledge in their academic or occupational fields (6%); to facilitate a change in their academic or occupational fields (5%); for leisure or personal interest (4%); to increase opportunities for promotion, advancement, or higher salary (3%); and for other reasons (4%).[9]

TABLE 2-6

Recent recipients of S&E degrees who attended community college, by sex, race and ethnicity, citizenship status, and parents' education level: 2015

(Number and percent)

Characteristic	Number	Percent
All recent S&E degree recipients who attended community college	1,262,000	47
Degree level		
Bachelor's	983,000	52
Master’s	279,000	36
Sex		
Female	657,000	50
Male	604,000	44
Race or ethnicity		
American Indian or Alaska Native	2,000	33
Asian	141,000	28
Black or African American	129,000	56
Hispanic or Latino[a]	231,000	64
Native Hawaiian or Other Pacific Islander	2,000	50
White	708,000	48
More than one race	49,000	62
Citizenship status		
U.S. citizen	1,214,000	53
Permanent visa	33,000	38
Temporary visa	15,000	5
Father’s education		
Less than high school	114,000	59
High school diploma or equivalent	265,000	53
Some college, vocational, or trade school	298,000	56
Bachelor’s	277,000	39

Characteristic	Number	Percent
Master's	173,000	47
Professional degree	62,000	39
Doctorate	47,000	31
Not applicable	26,000	51
Mother's education		
Less than high school	117,000	56
High school diploma or equivalent	272,000	53
Some college, vocational, or trade school	270,000	43
Bachelor's	366,000	47
Master's	165,000	46
Professional degree	26,000	41
Doctorate	22,000	32
Not applicable	23,000	61

[a] Hispanic may be any race. American Indian or Alaska Native, Asian, black or African American, Native Hawaiian or Other Pacific Islander, white, and more than one race refer to individuals who are not of Hispanic origin.

Note(s)

Recent S&E degree recipients are those who earned their bachelor's or master's degrees between 1 July 2008 and 30 June 2013. Data are rounded to the nearest 1,000.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2017), 2015 National Survey of College Graduates (NSCG).

Science and Engineering Indicators 2018

For-Profit Institutions

In 2015–16, about 1,300 degree-granting institutions in the United States operated on a for-profit basis; this number peaked at 1,451 in 2012–13 but has declined to 1,262 since then (NCES 2017). Four-year institutions accounted for slightly more than half of these institutions (55%) in 2015–16 (▦ Table 2-1).

For-profit institutions enroll considerably fewer students than public ones, particularly at the 2-year level—nearly 120,000 versus nearly 6.6 million in community colleges in 2015.[10] Enrollment and degrees awarded in for-profit institutions rose dramatically throughout the 2000s but declined in recent years (Appendix Table 2-2).[11]

Enrollment patterns differ among racial and ethnic groups. For-profit institutions play a disproportionate role in the education of blacks and Native Hawaiians or other Pacific Islanders, who are more likely than other racial or ethnic groups to enroll in private for-profit academic institutions (NSF/NCSES 2017a).

For-profit academic institutions are not large producers of S&E degrees: they awarded between 3% and 5% of S&E degrees at the bachelor's, master's, and doctoral levels, as well as 18% of S&E degrees at the associate's level in 2015 (Appendix Table 2-2). Computer sciences accounted for three-quarters of the associate's degrees and nearly half of the bachelor's degrees awarded by for-profit institutions in S&E fields in 2015 (Appendix Table 2-3). At the master's level, S&E degrees were mainly in psychology (38%), social sciences (32%), and computer sciences (27%); at the doctoral level, they were almost exclusively in psychology (79%) and social sciences (17%).

Distance and Online Education

Distance and online education enable institutions of higher education to reach a wider audience by expanding access for students in remote locations while providing greater flexibility for students who face time constraints, physical impairments, responsibility to care for dependents, and other challenges. Distance education has been around for more than 100 years (Perna et al. 2014), whereas online education is a relatively new phenomenon. Online education can serve individuals' needs for lifelong learning and skill retooling during times of rapid technological change.

Distance education uses technology to deliver instruction to students who are separated from the instructor and to support regular and substantive interaction between the students and the instructor, synchronously or asynchronously (Kena et al. 2016). Distance education enrollment has grown in recent years, given the growth of Internet technologies to deliver content. According to nationally representative data from the Integrated Postsecondary Education Data System (IPEDS) 2015 Fall Enrollment survey, 14% of all students in 4-year Title IV institutions (i.e., institutions that participate in federal financial aid programs) were enrolled exclusively in distance education courses, and another 15% were enrolled in distance education and regular on-campus courses; whereas the remaining 71% of these students were not enrolled in any distance education course (▦Table 2-7).[12] Exclusive enrollment in distance education courses was considerably higher at private for-profit 4-year institutions than at either 2- or 4-year public or private nonprofit institutions or at private for-profit 2-year institutions. Enrollment in some distance education courses was highest at public institutions. Exclusive enrollment in distance education courses was higher at the graduate level than at the undergraduate level, whereas enrollment in some distance education courses was higher at the undergraduate level than at the graduate level.

TABLE 2-7

Enrollment in Title IV institutions, by distance education enrollment status, control, and level of institution: Fall 2015

(Percent)

Institutional control and level	All (number)	Exclusively distance education courses	Some distance education courses	No distance education courses
Total enrollment				
Number	20,382,473	2,874,098	3,086,670	14,421,705
Percent	100	14.1	15.1	70.8
Degree level				
Undergraduate	1,744,188	12.1	16.3	71.6
Degree- or certificate-seeking	15,370,264	12.1	17.7	70.2
Non-degree- or certificate-seeking	1,770,924	13.8	6.5	79.7
Graduate	2,940,762	26.1	8.3	65.6
Control and level of institution				
Public				
2-year	6,271,901	11.4	17.7	70.9
4-year	8,352,437	8.9	18.1	73.1
Private nonprofit				
2-year	56,125	2.1	27.2	70.7
4-year	4,013,680	16.6	8.3	75.1
Private for-profit				
2-year	280,004	3.8	6.3	90.0
4-year	1,120,582	65.8	8.9	25.3
Institutional category				
All degree-granting	19,976,936	14.4	15.4	70.2
All non-degree-granting	405,537	0.6	1.1	98.4

Note(s)

Title IV institutions are those with a written agreement with the Secretary of Education that allows the institution to participate in any of the Title IV federal student financial assistance programs. Percentages may not add to 100% because of rounding.

Source(s)

National Center for Education Statistics, Integrated Postsecondary Education Data System (IPEDS), Fall 2015, Fall Enrollment component.

Science and Engineering Indicators 2018

Nationally representative data collected by the 2015 IPEDS Completions Survey also show that, regardless of the degree level, the proportion of distance education programs in S&E was highest at private for-profit 4-year institutions, ranging from nearly 30% of the S&E programs in these institutions at the associate's level to more than two-thirds of those at the master's level (Appendix Table 2-4). In general, computer sciences and psychology were the two fields where distance education programs were most prevalent, irrespective of institution type and degree level. In addition, engineering, engineering technologies, health technologies, and social sciences fields also had considerable utilization of distance education programs. (Between 18% and 25% of the master's programs in engineering, engineering technologies, and health technologies at public 4-year institutions and the majority of social sciences programs at private for-profit 4-year institutions had distance education.)

A recent study provided evidence that at a for-profit university with an undergraduate enrollment of more than 100,000 students where most of them were pursuing bachelor's degrees, taking a course online instead of in-person reduced student success and progress in college. Grades were lower not only in the course students took online but also in future courses. In addition, students who took a course online were less likely to remain enrolled a year later (Bettinger et al. 2017).

Allen et al.'s (2016) most recent survey showed that a small segment of higher education institutions had massive open online courses (MOOCs; see Glossary) (11%) or were planning one in 2015 (2%); however, most institutions decided against having a MOOC (59%) or remained undecided about it (28%). MOOCs can provide broad access to higher education for free or at a very low cost, facilitating lifelong learning and continuing education. Through their online platforms, MOOCs also have the potential to collect massive amounts of information that can be used to conduct experimental research on how people learn and to identify online practices that improve learning (ED/OET 2013).

Nationally representative data on MOOCs are not available. However, research conducted on the first 4 years of open online courses offered by HarvardX and MITx on the edX platform reveals that during that time, the platform included 290 courses, granted 245,000 certificates (including free and paid certificates), and had 4.5 million participants (Chuang and Ho 2016).[13] The survey of MOOCs showed that participants' median age was 29, two-thirds of them were males, 71% were from countries other than the United States, and 73% were bachelor's degree holders. The largest MOOCs were in computer sciences.

Overall completion rates in MOOCs are low; however, they varied according to participants' intentions at the start of the course. Some MOOC participants indicated that they intended to obtain a free certificate, others reported that they were exploring a subject, and others reported paying in order to verify their identity and obtain a formal certificate. Students who paid for a certificate verifying their completion of the MOOC were much more likely to obtain a certificate than those who took a class that offered a free certificate (60% compared with 8%).

Online education companies offering MOOCs have also expanded their offerings of certificate programs. For instance, Udacity partnered with AT&T to offer technology-focused "nanodegrees" teaching students a specific set of skills that can be applied to a job. These courses have been developed in partnership with employers. For example, Udacity developed a course on Android technology with Google and another on self-driving car engineering with Mercedes-Benz, NVIDIA, and Otto (*The Economist* 2017). For students, these courses are much more affordable than attending a college or university and provide the flexibility they need to complete them while balancing other family and job responsibilities. For businesses, these types of classes provide a quick response to market demand for niche technological specializations.

In 2014, the Georgia Institute of Technology (Georgia Tech), in collaboration with Udacity and AT&T, began to offer an online master's program in computer science, which combines MOOC-like course videos and assessments with a support system that works directly with students. The university's goal was to create a master's degree program that was just as rigorous as the one offered on campus but at a much lower cost. A recent study focusing on the students who applied to this program showed that access to this online option increased overall enrollment in higher education, rather than substitute for the brick-and-mortar university options (Goodman et al. 2016). The researchers found that online students in this program were older than students in the on-campus program and that the vast majority of them were employed. They also found that the demand for Georgia Tech's online degree satisfied previously unmet demand for mid-career training and could increase the production of computer sciences master's degrees in the United States. Overall, their results also suggested that high-quality online education may open opportunities for people who otherwise would not be pursuing a degree.

Changing modes of online education are prompting questions about how the use of this technology will affect the higher education sector. In particular, it is not yet clear how many students can sustain commitment to learning in the absence of more personal contact and to what extent the growing access to higher education facilitated by MOOCs will translate into learning and, in the long run, to higher levels of educational achievement. It is also not clear how these models can be applied in a wider range of disciplines and higher education institutions.

Trends in Higher Education Expenditures and Revenues

Higher education spending and revenue patterns have changed substantially since 2000, in trends that intensified during the economic downturn of the late 2000s. Although all types of higher education institutions faced competing demands in a stringent budget environment, each type faced unique challenges. Through 2010, increases in the number of students seeking an affordable college education compounded the challenges created by tight budgets. Despite declines in enrollment between 2011 and 2015 (Appendix Table 2-5), the same challenges have remained. This section shows trends in inflation-adjusted average spending and revenue per full-time equivalent (FTE) student from 2000 to 2015,[14] based on data from the Delta Cost Project.[15]

Very High Research Universities—Public and Private Institutions

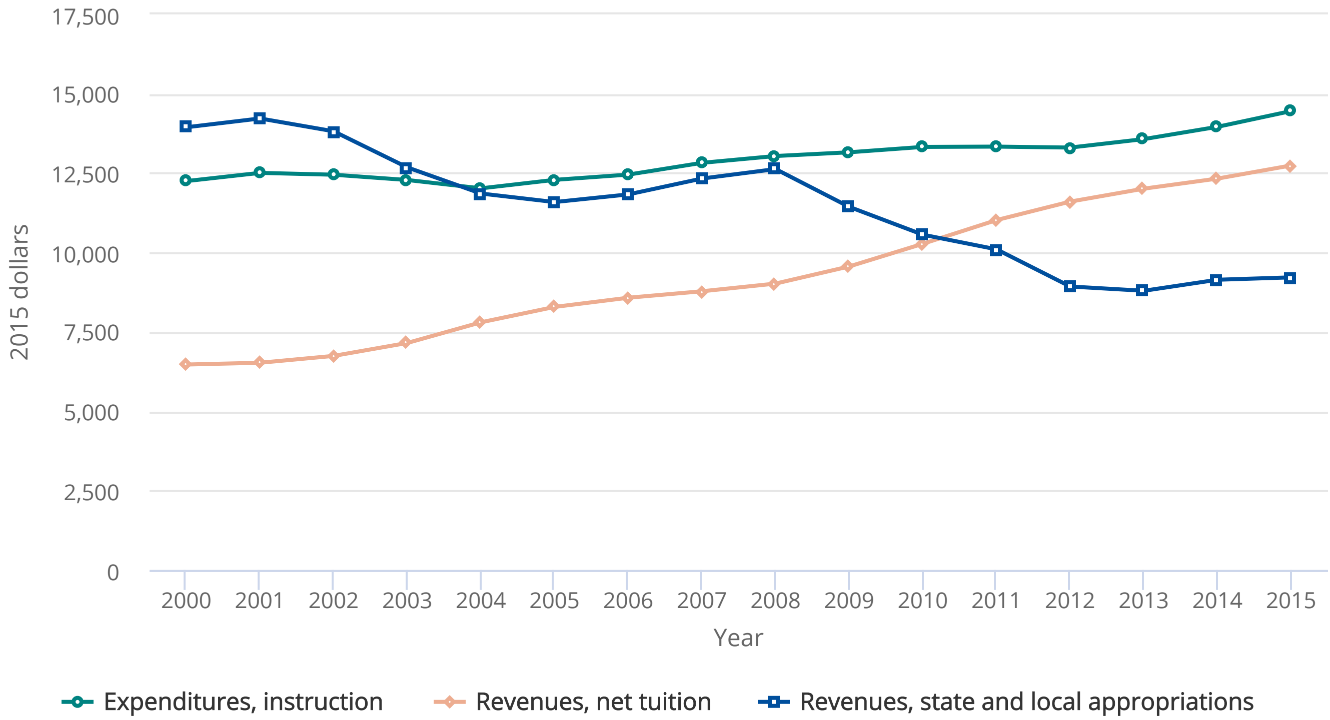
Revenues

Net tuition and federal appropriations, grants, and contracts are two large sources of revenues for public and private very high research institutions (Appendix Table 2-6).[16] For public institutions, state and local appropriations are also critical, supplying an amount of revenue just under three-quarters of net tuition ($9,200 per FTE in 2015); in contrast, they are a small source of revenue for their private counterparts (about $1,100 per FTE in 2015 and only about 4% of net tuition). Much more important for private institutions are private and affiliated gifts, investment returns,[17] and endowment income, which are usually the largest sources of revenue other than funds from hospitals and other independent operations.[18]

State and local appropriations for public very high research universities have declined since 2000, with a particularly steep drop between 2008 and 2012 (📊 Figure 2-1). This decline coincided with a compensating increase in net tuition. In 2000, average state appropriations per FTE at public very high research institutions were more than twice the amount of net tuition ($13,900 versus $6,500). By 2015, however, appropriations had dropped to $9,200 per FTE, whereas net tuition had increased from about $6,500 to more than $12,700 per FTE (Appendix Table 2-6). This change represents a downward shift in higher education investment by state and local governments, resulting in a higher financial burden for individual students and their families. Starting at a higher level, net tuition at private very high research universities also increased during this 15-year period. But the increase, from about $22,700 to almost $27,700, was proportionally much smaller.

FIGURE 2-1

Selected average revenues and expenditures per FTE at public very high research universities: 2000–15



FTE = full-time equivalent.

Source(s)

Integrated Postsecondary Education Data System (IPEDS) Analytics: Delta Cost Project Database, 2000–15 (16-year matched set), special tabulations (2017).

Science and Engineering Indicators 2018

Revenue from federal appropriations, grants, and contracts, the source used for most research expenditures, is highest at the most research-intensive universities (Appendix Table 2-6), particularly the private ones. These revenues increased steadily from 2000 to 2005, dipped as the economy entered the recession at the end of the decade, increased somewhat with American Recovery and Reinvestment Act (ARRA) funding, then dipped again between 2011 and 2015. Between 2000 and

2015, revenue per FTE from these funds increased by 11% at public very high research institutions to just under $8,000 per FTE and by 14% to $25,700 per FTE at their private counterparts.

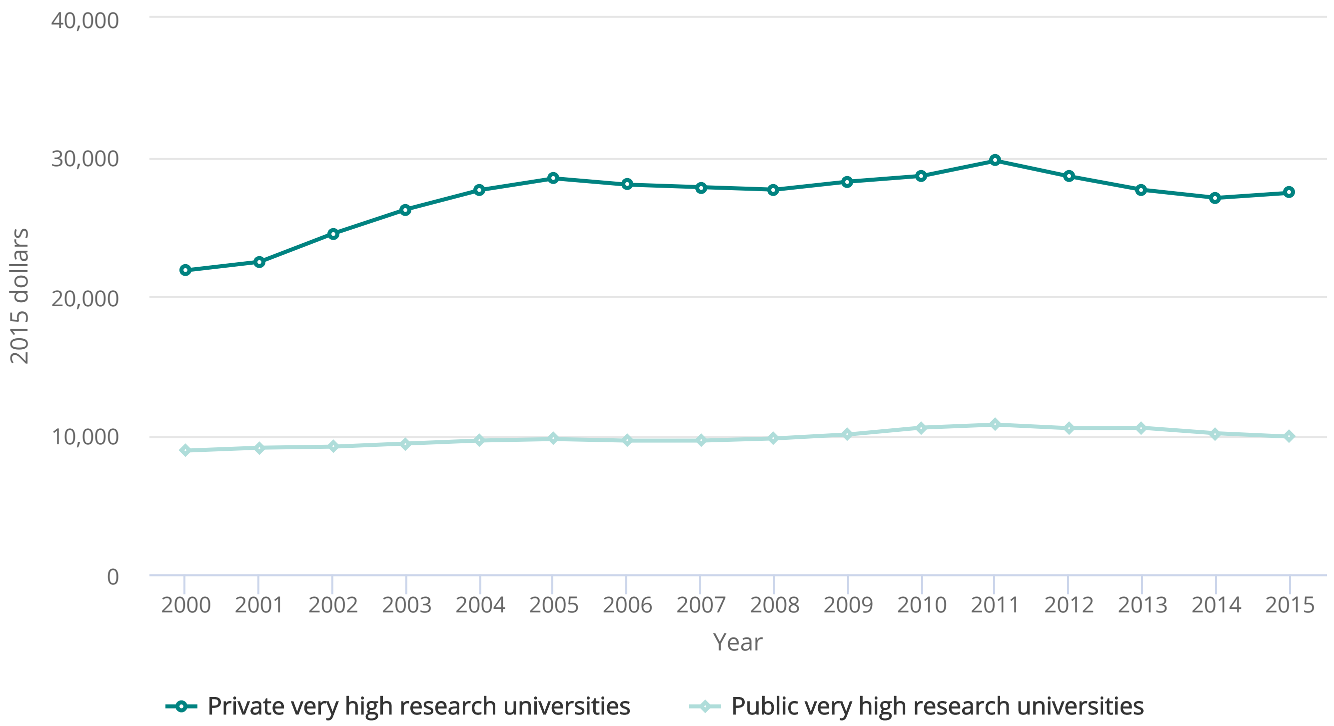
Expenditures

Research and instruction are the two largest core education expenditures at public and private very high research universities. Between 2000 and 2015, research expenditures per FTE increased substantially at both types of institutions—by 25% at private universities and by 11% at their public counterparts (📊Figure 2-2; Appendix Table 2-7). For public and private institutions, research expenditures per FTE peaked in 2011 (coinciding with the year of greatest ARRA research spending); since then, they have declined by about 8%. See Chapter 5 section Academic R&D, by Public and Private Institutions for greater detail on university research spending.

Instructional spending per FTE followed a pattern similar to that of research expenditures, increasing at a higher rate at private very high research institutions than at their public counterparts. Between 2000 and 2015, instructional expenditures per FTE increased by 43% at private universities compared to 18% at public universities. Moreover, for the past decade, instructional spending at private very high research universities has been three times that of the public universities (📊Figure 2-3).

FIGURE 2-2

Average expenditures per FTE on research at public and private very high research universities: 2000–15



FTE = full-time equivalent.

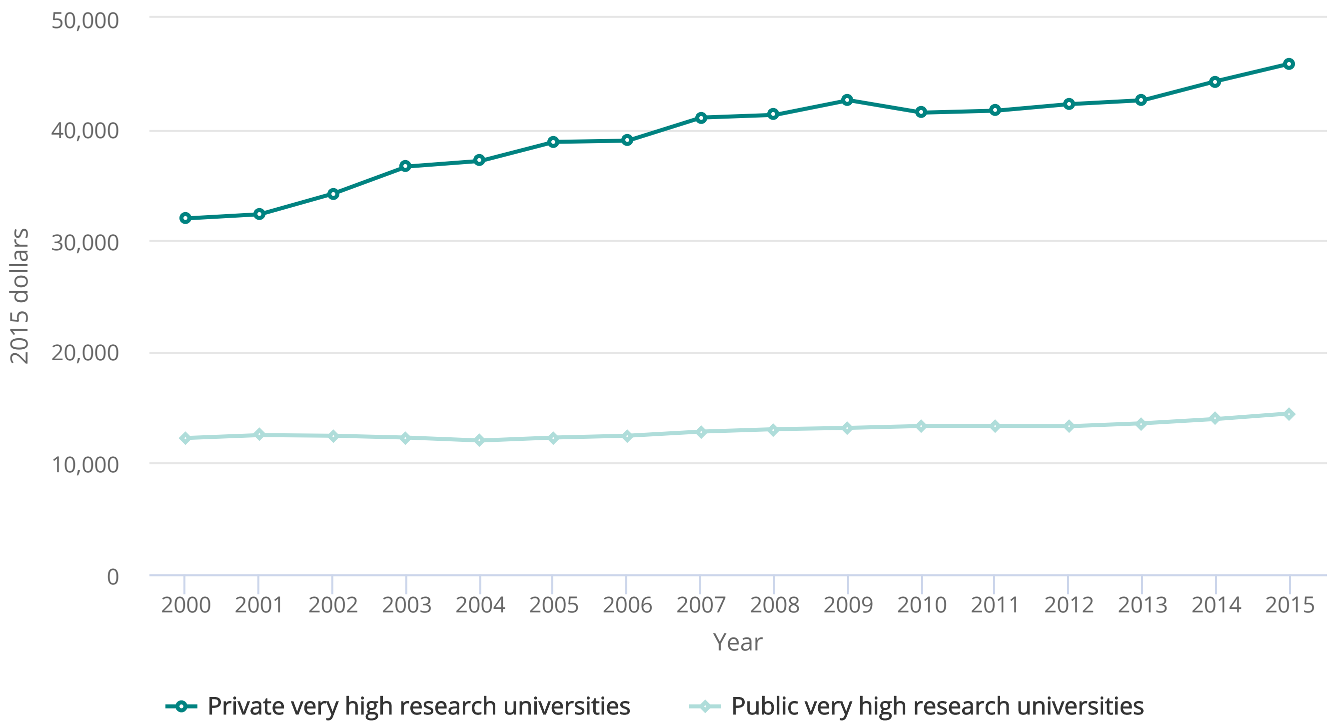
Source(s)

Integrated Postsecondary Education Data System (IPEDS) Analytics: Delta Cost Project Database, 2000–15 (16-year matched set), special tabulations (2017).

Science and Engineering Indicators 2018

FIGURE 2-3

Average expenditures per FTE on instruction at public and private very high research universities: 2000–15



FTE = full-time equivalent.

Source(s)

Integrated Postsecondary Education Data System (IPEDS) Analytics: Delta Cost Project Database, 2000–15 (16-year matched set), special tabulations (2017).

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Four-Year and Other Graduate Public Institutions

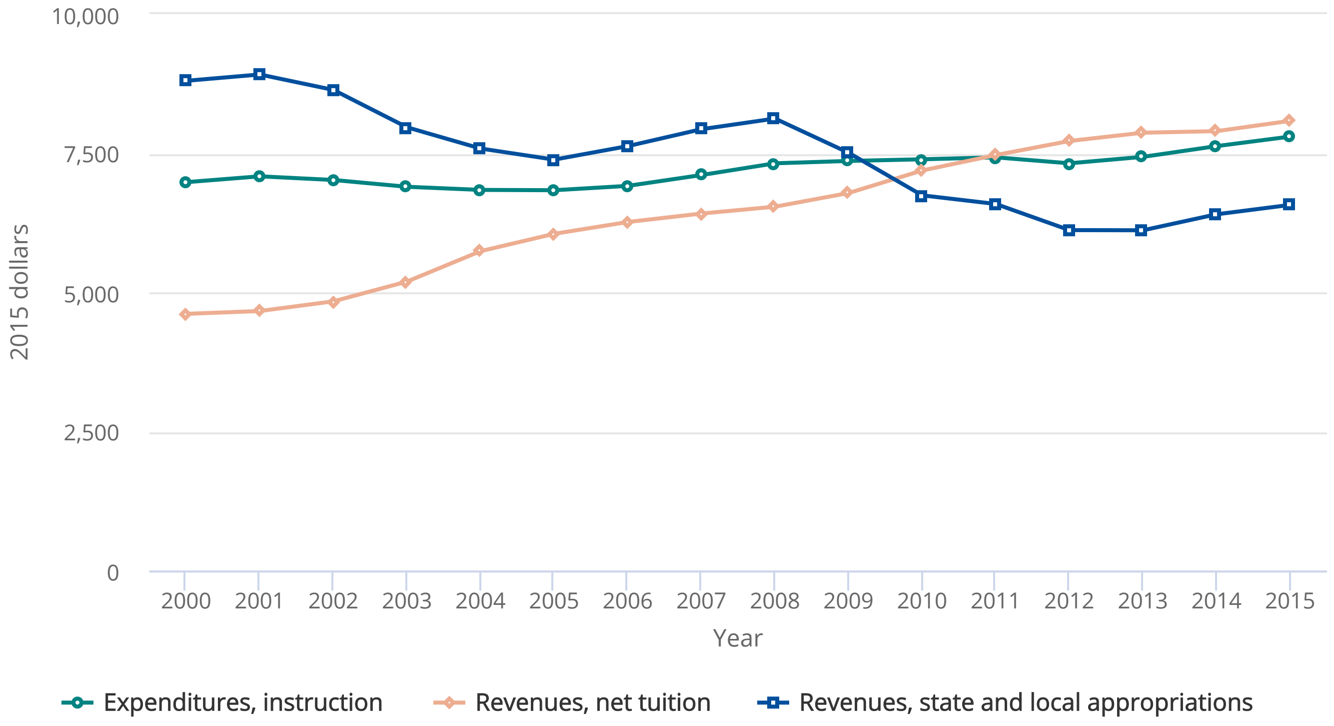
Revenues

From 2000 to 2015, state and local appropriations and net student tuition were the largest sources of revenues centrally involved with education at other public institutions offering 4-year and graduate degrees (Appendix Table 2-6).[19] At these institutions, total revenues from these two sources were lower than those at public very high research universities. In 2015, net student tuition per FTE was higher at public 4-year institutions than at community colleges but state and local appropriations per FTE were lower. From 2000 through 2015, the percentage drop in revenue per FTE from state and local appropriations (25%) was somewhat less than that experienced at the public very high research institutions (34%). In 2010, net student tuition replaced state and local appropriations as the largest source of revenue in the public 4-year institutions. Average state appropriations per FTE in 2000 ($8,800) were almost twice as large as tuition revenue ($4,600). By 2010, average revenues from net student tuition, at $7,200 per FTE, exceeded average revenues from state appropriations per FTE by about

$450. By 2015, average revenues from net tuition increased even further, to more than $1,500 over the average revenues from state appropriations (Figure 2-4). As in the case of public very high research institutions, this change represents a shift in financial investment from state and local governments to individual students and their families.

FIGURE 2-4

Selected average revenues and expenditures at public 4-year and other postsecondary institutions: 2000–15



Note(s)

Data are per full-time equivalent. Four-year and other postsecondary institutions include doctorate-granting universities—high research activity, doctoral/research universities, master's colleges and universities, and baccalaureate colleges, according to the 2010 Carnegie Classification of Institutions of Higher Education.

Source(s)

Integrated Postsecondary Education Data System (IPEDS) Analytics: Delta Cost Project Database, 2000–15 (16-year matched set), special tabulations (2017).

Science and Engineering Indicators 2018

Expenditures

Spending on instruction at 4-year and other graduate public institutions has been at least three times as high as almost all the other standard expense categories. It increased from an average of nearly $7,000 per FTE in 2000 to about $7,800 per FTE in 2015 (Appendix Table 2-7). Other expenditures represented much smaller shares of total spending; most of these expenditures increased, with average increases between 2000 and 2015 ranging from 5% for spending on plant operation and maintenance to 28% for student services.

Community Colleges

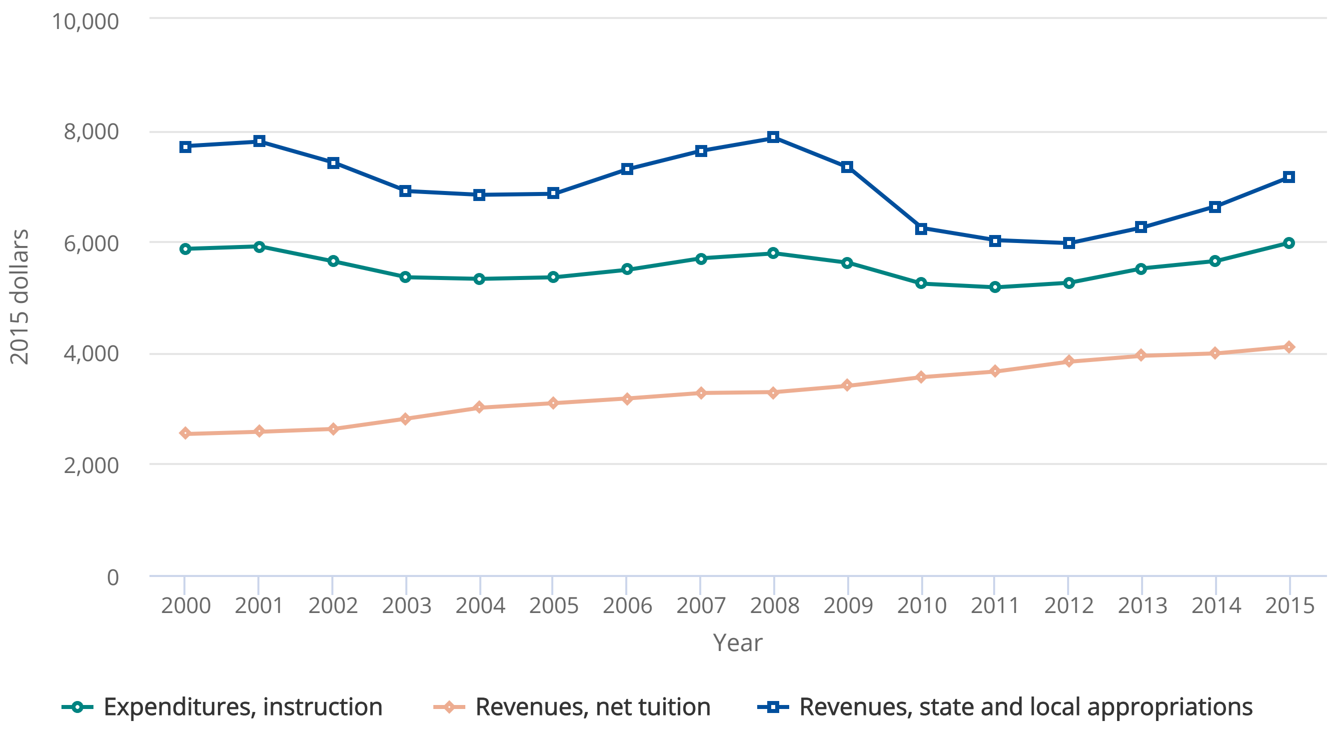
Revenues

Revenues are much lower for community colleges than for other public institutions of higher education, particularly public very high research institutions.[20] As in the other public institutions, the main sources of revenue at community colleges are state and local appropriations and net student tuition (Appendix Table 2-6). In 2015, average revenues from state and local appropriations at community colleges were about $7,200 per FTE, compared with about $9,200 at public very high research institutions; average revenues from net tuition were about $4,100 per FTE, compared with about $12,700 at public very high research institutions. Unlike other public institutions, revenue from state and local appropriations at community colleges still exceeded net tuition revenue in 2015.

Even so, community colleges have experienced the same decline in state and local government support that other public institutions have seen. Between 2000 and 2015, revenues from state and local appropriations at community colleges decreased from an average of about $7,700 per FTE to $7,200 per FTE, with a steady decline from 2008 to 2012. This trend has since begun to reverse, although state and local support remain below their prerecession levels (📊Figure 2-5). As state support declined from 2008 to 2012, revenues from net tuition increased by 17%. In 2000, revenues from state and local appropriations represented 56% of total revenues at community colleges, and tuition accounted for 18%. By 2015, state and local appropriations had dropped to 48% of total revenues, whereas the proportion of revenues from tuition increased to 28% of total revenues.

FIGURE 2-5

Selected average revenues and expenditures per FTE at community colleges: 2000–15



FTE = full-time equivalent.

Note(s)

Community colleges are public associate's colleges according to the 2010 Carnegie Classification of Institutions of Higher Education.

Source(s)

Integrated Postsecondary Education Data System (IPEDS) Analytics: Delta Cost Project Database, 2000–15 (16-year matched set), special tabulations (2017).

Science and Engineering Indicators 2018

Expenditures

Expenditures are also much lower for community colleges than for other public institutions of higher education. In community colleges, instruction is by far the largest expenditure (Appendix Table 2-7). In 2000, spending on instruction was about $5,900 per FTE, about 40% of total expenditures. In 2015, average instructional spending per FTE ($6,000) was very similar in size to the 2000 level. Overall, these expenditures went up and down between 2000 and 2015, declining from 2001 to 2005 and 2008 to 2012 but increasing during other years (Figure 2-5).[21] Expenditures on student services and institutional and academic support declined in the late 2000s but increased somewhat in 2012–15. Expenditures in plant operation and maintenance also declined between 2008 and 2011 and have risen slightly since then. As a percentage of total expenditures, each spending stream remained relatively constant from 2000 through 2015.

Public Institutions Comparison

Revenues

Between 2000 and 2015, revenues from state and local appropriations and net tuition, the main two revenue sources at public institutions, when added together increased by similar amounts at community colleges (10%) and 4-year institutions (9%); they increased a little less at very high research institutions (8%). States and localities cut funding for all three categories of institutions, but the reduction was smaller in the community colleges (7%) than in the public very high research institutions (34%) and the public 4-year and other graduate public institutions (25%). Unlike community colleges, however, the other two types of public institutions were able to increase revenues from net tuition to a greater extent. FTE net tuition revenues increased by 97% at the public very high research universities and by 75% at the 4-year and other graduate public institutions, compared with 62% at community colleges (Appendix Table 2-6).

Expenditures

Instruction expenditures followed a different pattern. They rose most rapidly at the public very high research institutions (18%), where there was pressure to keep faculty salaries (a major component of instructional expenses) competitive with those of their private counterparts, which spent more on instruction to begin with and were increasing these expenses even more rapidly (43%) (Appendix Table 2-7). At community colleges, FTE instructional expenses increased by 2% over the period from 2000 to 2015,[22] whereas in 4-year and other graduate institutions, they increased by 12%. Overall, during this period, community colleges had more limited resources and less flexibility to draw on alternate revenue sources to support their instructional expenses. However, given the decline in enrollment in fall 2012 through fall 2015 after the recession, average expenditures in instruction increased more substantially (14%) at community colleges and in 2015 were at their highest level since 2001 (see section Undergraduate Enrollment in the United States).

Financing Higher Education

Cost of Higher Education

Affordability and access to U.S. higher education institutions are continuing concerns (Sullivan et al. 2012; GAO 2014). According to the College Board (2016a), the estimated average net tuition and fees (i.e., the published prices minus grant aid and tax benefits) vary by institution type.

In the last 10-year period ending in 2016–17, net tuition and fees paid by full-time, in-state undergraduate students in public 4-year colleges increased by about 30% in constant 2016 U.S. dollars (College Board 2016a; ▦ Table 2-8). Net tuition and fees at these institutions had dipped during the recessionary period between 2007–08 and 2009–10, but they increased by 70% since then and nearly 10% in the last 2 years.

At private nonprofit institutions, net tuition and fees followed a similar path in the last 10 years, declining between 2007–08 and 2011–12 but rising since then, gradually approaching its highest point 10 years earlier.

At public 2-year colleges, net tuition and fees have overall declined by more than 200% in the last 10 years, but they have increased by about 35% since 2011–12 (▦ Table 2-8). On average, since 2009–10, undergraduate students enrolled full time at public 2-year colleges have received enough funding through grant aid and federal education tax credits and deductions to cover tuition and fees, and they can use the rest of those funds to cover books or living expenses (their net tuition was –$500 in 2016–17) (College Board 2016a). Despite large percentage tuition increases in public institutions, they are still more affordable than their private counterparts.

TABLE 2-8

Net tuition and fees for full-time undergraduate students by institutional control: 2006–07 and 2011–12 through 2016–17

(2016 U.S. dollars)

Institutional control	2006–07	2011–12	2012–13	2013–14	2014–15	2015–16	2016–17[a]
Public 2-year	420	-770	-610	-620	-620	-560	-500
Public 4-year[b]	2,910	3,100	3,410	3,370	3,430	3,620	3,770
Private nonprofit 4-year	14,900	12,770	13,000	12,980	13,050	13,310	14,190

[a] Estimated value.

[b] In-state students.

Note(s)

Prices have been rounded to the nearest $10. Net tuition and fees equal published tuition and fees minus total grant aid and tax benefits.

Source(s)

The College Board, *Annual Survey of Colleges, Trends in College Pricing* (2016).

Science and Engineering Indicators 2018

Between 1999–2000 and 2011–12, changes in the net cost of higher education for dependent undergraduates varied by family income level and type of institution they attended (Table NSB 2016 2-9; the NCES National Postsecondary Student Aid Study [NPSAS] is conducted every 4 years, so there are no new data). For students from higher-income families, net tuition and fees increased across all types of institutions. Students from lower-income families experienced declining or stable net tuition in certain types of institutions while seeing increases in others. (On average, these students experienced declines at public 2-year institutions; saw no changes at public and private nonprofit 4-year master's and baccalaureate institutions, as well as at private nonprofit 4-year research and doctoral institutions; and saw a rise at public 4-year research and doctoral institutions.)

Research suggests that the vast majority of low-income, high-achieving high school seniors do not apply to any selective college, although selective institutions cost them less than nonselective ones because of the large amounts of financial aid they are able to offer (Hoxby and Avery 2013).[23]

Undergraduate Financial Support Patterns and Debt

Financial Support for Undergraduate Education

With rising tuition, students increasingly rely on financial aid to fund their education. Financial aid for undergraduate students comes mainly in the form of student loans (federal and nonfederal), grants (federal, state, institutional, and private), and tuition tax credits. A financial aid package may contain one or more of these kinds of support. In 2016–17, undergraduate students received $184 billion in federal, state, institutional, and other aid, excluding nonfederal loans (College Board 2016b).

In the last 10 years, federal financial aid has constituted about two-thirds of the undergraduate student aid package; federal loans have been the main component, followed by federal grants, although the proportion of undergraduate students receiving federal loans declined (from 42% in 2005–06 to 33% in 2016–17), whereas the proportion receiving federal grants increased (from 18% to 23%). In addition, institutional grants increased (from 20% to 23%), and private and employer grants and state grants rose slightly as well (6% versus 7% in both cases).

According to the latest data available from the NPSAS, a higher proportion of undergraduates in private institutions than those in public institutions received some type of financial aid and incurred student loans (Ifill and Shaw 2013).[24]

Undergraduate Debt

Among recent graduates with S&E bachelor's degrees, the level of undergraduate debt does not vary much by undergraduate major, although it is somewhat lower for recent recipients of engineering bachelor's degrees than for recent recipients of bachelor's degrees in social and related sciences and in physical and related sciences.[25]

Levels of debt vary to a greater extent by type of institution. The extent of undergraduate indebtedness of students from public colleges and universities is almost as high as that for students from private nonprofit universities (about 60% at graduation). The level of debt differs, however: about $26,800 per borrower for those graduating from a public institution and $31,400 for those graduating from private nonprofits. Students who attend private for-profit institutions are more likely to borrow, and to borrow larger amounts, than those who attend public and private nonprofit institutions (College Board 2016b).

Levels of debt varied widely by state. Average debt for 2014 graduates of public 4-year colleges and universities ranged from $18,800 in New Mexico to $35,000 in New Hampshire. Average debt for graduates of private nonprofit colleges and universities ranged from $8,900 in Alaska to $36,200 in Connecticut (Institute for College Access & Success, College InSight 2016). Cost of living may account for some of the differences by state.[26]

Graduate Financial Support Patterns and Debt

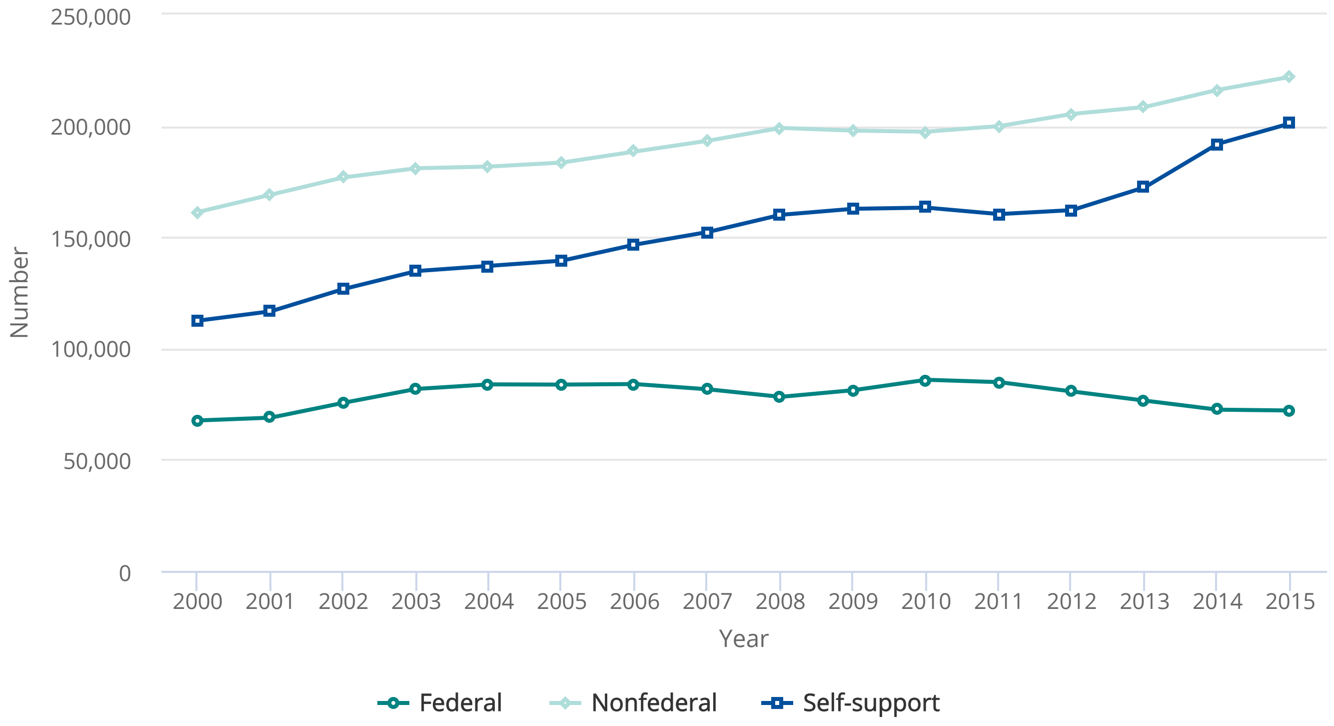
Financial Support for S&E Graduate Education

In 2015, nonfederal funds were the main source of funding of full-time S&E graduate students (45%), followed by self-support (41%), and federal funds (15%) (Appendix Table 2-8). Nonfederal sources include state funds and funding from universities, employers, nonprofit organizations, and foreign governments. Particularly in the large public university systems, state funds are affected by the condition of overall state budgets. Self-supporting graduate students rely primarily on loans, their own funds, or family funds for financial support.

The number of full-time graduate students supported primarily by nonfederal sources or through self-support has increased in the last 15 years, with the steepest increase in 2014 (📊Figure 2-6).[27] The proportion of self-supporting graduate S&E students gradually rose from 33% to 41% between 2000 and 2015, primarily because of increasing enrollment of master's students on temporary visas who are mostly self-supporting (IIE 2016; NSF/NCSES 2016).[28] Self-support was highest (60% or higher) among full-time graduate students in computer sciences and in medical and other health sciences (Appendix Table 2-9).

FIGURE 2-6

Full-time S&E graduate students, by source of primary support: 2000–15



Note(s)

Self-support includes any loans (including federal) and support from personal or family financial contributions. In 2007, the survey was redesigned to improve reporting. In 2014, the survey frame was updated with academic institutions with S&E master's- or doctorate-granting programs not included previously. Because of methodological changes, data should be used with caution for trend analysis. S&E includes health fields (medical sciences and other health sciences) and excludes newly eligible fields (architecture, communication, and family and consumer sciences/human sciences) added starting in 2007. Therefore, the S&E numbers in this table differ from the data used in the Survey of Graduate Students and Postdoctorates in Science and Engineering (GSS) (annual series) and elsewhere.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2016), 2015 GSS.

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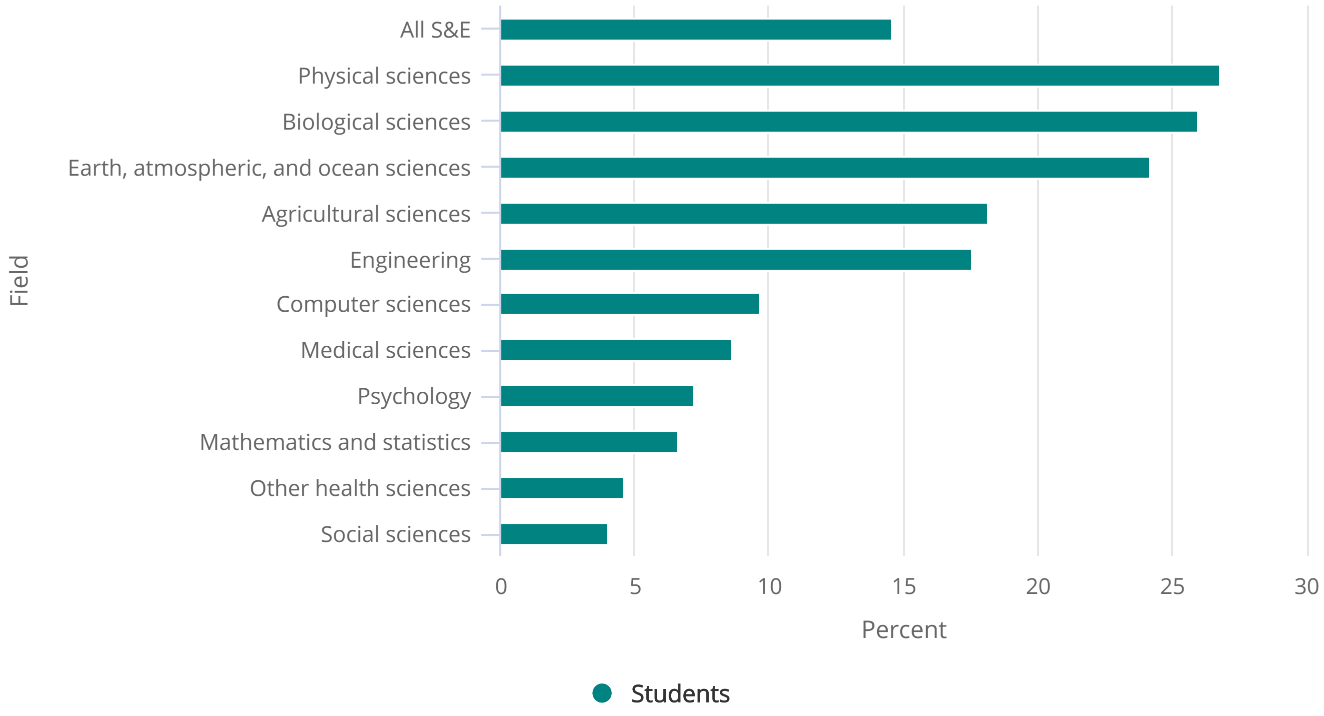
The number of full-time S&E graduate students supported by the federal government increased between 2000 and 2004 and was fairly stable through 2010, but it declined by 16% in the last 5 years, with the steepest decline between 2011 and 2014 (Appendix Table 2-8). Between 2000 and 2006, the proportion of full-time S&E students primarily supported by the federal government remained fairly stable at 20%–21% but has declined since then, reaching its lowest level in at least 16 years in 2015 (15%) (Appendix Table 2-10). This decline was more pronounced in the biological, physical, and medical sciences (Appendix Table 2-10).

The federal government plays a substantial role in supporting full-time S&E graduate students in some fields but a smaller role in others. Federal financial support for graduate education reaches a larger proportion of students in the physical sciences; the biological sciences; the earth, atmospheric, and ocean sciences; and engineering (Figure 2-7; Appendix Table 2-11). For some mechanisms of support, the federal role is fairly large. In 2015, the federal government funded 55% of full-time S&E graduate students who were on traineeships, 45% of those with research assistantships (RAs), and 22% of those with fellowships (Appendix Table 2-11).

FIGURE 2-7

Full-time S&E graduate students with primary support from federal government, by field: 2015



Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2016), 2015 Survey of Graduate Students and Postdoctorates in Science and Engineering (GSS).

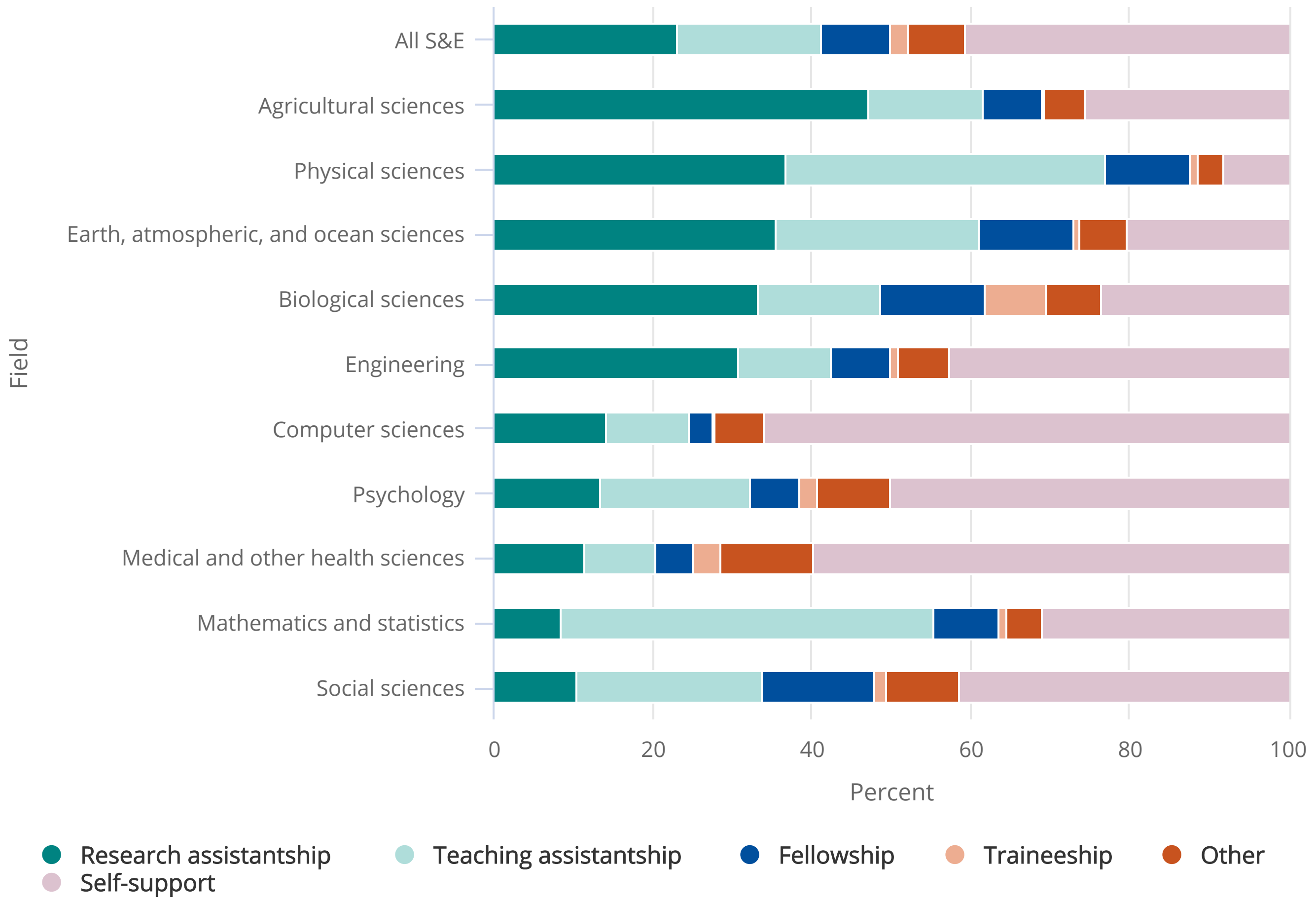
Science and Engineering Indicators 2018

Teaching assistantships (TAs) are generally institutionally funded. Most graduate students, especially those who pursue doctoral degrees, are supported by more than one source or mechanism during their time in graduate school, and some receive support from several different sources and mechanisms in any given academic year. Primary mechanisms of support differ widely by S&E field of study (Figure 2-8; Appendix Table 2-9). In 2015, full-time graduate students in physical sciences were financially supported mainly through TAs (40%) and RAs (37%). RAs were also important in agricultural sciences (47%);

earth, atmospheric, and ocean sciences (36%); biological sciences (33%); and engineering (31%; in particular, in materials and chemical engineering). In mathematics and statistics, nearly half (47%) of the full-time students were supported primarily through TAs.

FIGURE 2-8

Full-time S&E graduate students, by field and mechanism of primary support: 2015



Note(s)

Self-support includes any loans (including federal) and support from personal or family financial contributions.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2016), 2015 Survey of Graduate Students and Postdoctorates in Science and Engineering (GSS).

Science and Engineering Indicators 2018

Most federal financial support for graduate education is in the form of RAs funded through grants to universities for academic research. RAs are the primary mechanism of support for 71% of federally supported full-time S&E graduate students

(Appendix Table 2-8). Fellowships and traineeships are the means of funding for 22% of the federally funded full-time S&E graduate students. For students supported through nonfederal sources in 2015, TAs (i.e., institutional funds) were the most prominent mechanism (40%), followed by RAs (29%).

NSF and the National Institutes of Health (NIH) support most of the full-time S&E graduate students whose primary support comes from the federal government, followed by the Department of Defense (DOD) (Appendix Table 2-12). In 2015, NSF supported about 23,000 S&E graduate students, NIH about 21,000, and DOD about 8,000. Trends in federal agency support of graduate students show considerable increases from 2000 to 2015 in the proportion of students funded by NSF, from 22% to 32% (Appendix Table 2-12). NSF supported 58% of students in computer sciences or mathematics whose primary support comes from the federal government; 51% of those in earth, atmospheric, and ocean sciences; 42% of those in the physical sciences; and 39% of those in engineering overall (about 49% of those in electrical engineering and 48% of those in chemical engineering) (Appendix Table 2-13). The proportion of students funded by NIH increased from 29% to 33% between 2000 and 2008 but has since decreased to 29%. In 2015, NIH funded about 70% of such students in the biological sciences, 57% of those in the medical sciences, and 36% of those in psychology. The proportion of graduate students supported by DOD has been relatively stable around 10%–12% in the last 15 years. In 2015, DOD supported 47% of the S&E graduate students in aerospace engineering, 31% of those in industrial engineering, 27% of those in electrical engineering, and 22%–23% of those in materials and mechanical engineering and in computer sciences.

For doctoral degree students, notable differences exist in primary support mechanisms by type of doctorate-granting institution (▦ Table 2-9). In 2015, RAs were the primary support mechanism for S&E doctorate recipients from research universities (i.e., doctorate-granting institutions with very high research activity, that receive the most federal funding, and those with high research activity). For those from medical schools, which are heavily funded by NIH, fellowships or traineeships accounted for the main mechanism of support. Students at less research-intensive universities relied mostly on personal funds.

TABLE 2-9

Primary support mechanisms for S&E doctorate recipients, by 2010 Carnegie classification of doctorate-granting institution: 2015

(Percent distribution)

Mechanism	All institutions	Research universities — very high research activity	Research universities — high research activity	Doctoral/ research universities	Medical schools and medical centers	Other or not classified
Doctorate recipients (number)	41,576	30,454	7,132	1,711	1,333	946
All mechanisms	100.0	100.0	100.0	100.0	100.0	100.0
Fellowship or traineeship	20.0	22.2	11.8	10.8	30.9	13.8
Grant	6.4	6.8	3.1	2.3	20.6	4.7
Teaching assistantship	16.6	16.6	22.8	8.2	1.4	7.6
Research assistantship	33.0	36.1	29.7	9.9	23.7	11.4
Personal	8.9	5.4	14.1	41.6	9.5	25.3
Other	3.6	3.0	5.3	6.1	4.7	3.2
Unknown	11.5	10.0	13.3	21.0	9.2	34.0

Note(s)

Personal support mechanisms include personal savings, other personal earnings, other family earnings or savings, and loans. Research assistantships include research assistantships and other assistantships. Traineeships include internships and residencies. Other support mechanisms include employer reimbursement or assistance, foreign support, and other sources. Percentages may not add to total because of rounding.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2016), 2015 Survey of Earned Doctorates (SED).

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Notable differences also exist in primary support mechanisms for doctoral degree students by sex, race and ethnicity, and citizenship (Appendix Table 2-14). In 2013–15, among U.S. citizens and permanent residents, male S&E doctorate recipients were more likely than their female peers to be supported by RAs (31% compared with 22%). Female S&E doctorate recipients were more likely than their male counterparts to receive fellowships or traineeships (28% versus 24%) and to support themselves from personal sources (18% versus 10%). Also, Asians were more likely than any other racial or ethnic group to have primary RA support (32%), followed by whites (28%). Compared with other racial and ethnic groups, Hispanic and American Indian or Alaska Native S&E doctorate recipients depended more on fellowships or traineeships (34% and 38%, respectively), and blacks and American Indians or Alaska Natives were more likely to use personal sources (28% and 19%, respectively). S&E doctorate recipients on temporary visas were more likely to have an RA (51%) than their U.S. citizen and permanent resident peers (27%); this has been a long-standing pattern. S&E doctorate recipients who were temporary visa holders were also less likely than U.S. citizens and permanent residents to use personal funds.

To some extent, the sex, citizenship, and racial and ethnic differences in types of support mechanisms are related to differences in field of study. White and Asian men, as well as international doctoral degree students, are more likely than white and Asian women, along with underrepresented minority students of both sexes, to receive doctorates in engineering and physical sciences (see Appendix Table 2-14), fields that are largely supported by RAs. In turn, women and underrepresented minorities are more likely to receive doctorates in social sciences (except for economics) and psychology, in which self-support is prevalent. However, some differences in type of support by sex, race and ethnicity, or citizenship remain after accounting for these doctoral field patterns. In 7 out of the 10 broad S&E fields presented in Appendix Table 2-14, men were more likely than women to have had RA as primary sources of support during their doctoral studies. In contrast, in 7 out of the 10 broad S&E fields, women were more likely to have used personal funds as a source of support. When looking at race and ethnicity patterns in primary source of support among U.S. citizen and permanent residents, in 8 out of the 10 S&E broad fields, Asians and whites were more likely to have used RA as primary source of support than underrepresented minorities. Underrepresented minorities (blacks in particular) were more likely than Asians and whites to have used personal funds as primary source of support in all the broad S&E fields (Appendix Table 2-14).

Overall, the variation in the use of RAs and personal funds as primary sources of support among doctorate recipients was also largely visible at very high research intensive institutions.[29]

Graduate Debt

At the time of doctoral degree conferral, 43% of 2015 S&E doctorate recipients had debt related to their undergraduate or graduate education. In 2015, 29% of S&E doctorate recipients reported having undergraduate debt and 32% reported having graduate debt. For some S&E doctorate recipients, debt levels were high, especially for graduate debt: 6% reported more than $40,000 of undergraduate debt, 13% reported more than $40,000 of graduate debt, and 18% reported more than $40,000 in cumulative undergraduate and graduate debt (Appendix Table 2-15).

Levels of debt vary widely by doctoral field. A higher percentage of doctorate recipients in non-S&E fields (52%) than those in S&E fields (32%) reported graduate debt. In 2015, within S&E, high levels of graduate debt were most common among doctorate recipients in the social sciences, psychology, and the medical and other health sciences. The proportion of doctorate recipients in these fields who reported graduate debt has increased since 2003.[30] Psychology doctorate recipients were most likely to report having graduate debt and high levels of debt.[31] In 2015, 27% of doctorate recipients in psychology reported graduate debt of more than $70,000 (Appendix Table 2-15). Doctorate recipients in mathematics, computer sciences, and physical sciences were the least likely to report graduate debt.

Men and women differed little in level of undergraduate debt, but women were more likely to have accumulated higher graduate debt. U.S. doctorate holders accumulated more debt than temporary visa holders. Regardless of broad field of doctorate, among U.S. citizen and permanent resident doctorate recipients with graduate-school debt, blacks, Hispanics, and American Indians and Alaska Natives were more likely to have debt over $30,000 than Asians and whites (NSF/NCSES 2017b, table 41). In all broad fields of study, blacks were more likely to have reported graduate-school debt higher than U.S. $30,000, followed by Hispanics and American Indian or Alaska Natives. In contrast, Asians and whites were the least likely racial group to report more than U.S. $30,000 in graduate-school debt. A higher level of graduate-school debt among underrepresented minority doctorate recipients than among their Asian and white counterparts, in all broad fields of study, was also observed at very high research intensive institutions.[32]

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[1] For a crosswalk between the Classification of Instructional Programs codes and the academic fields in completion tables, see https://webcaspar.nsf.gov/Help/dataMapHelpDisplay.jsp?subHeader=DataSourceBySubject&type=DS&abbr=DEGS&noHeader=1&JS=No, accessed 1 March 2017.

[2] Special tabulation from the Survey of Earned Doctorates.

[3] Tribal colleges and universities (TCUs) are fully accredited academic institutions designated by law. TCUs include institutions cited in the Equity and in Educational Land-Grant Status Act of 1994 and any other institution that qualifies for funding under the Tribally Controlled Community College Assistance Act of 1978.

[4] Being a high-Hispanic-enrollment institution (public and private nonprofit institutions whose undergraduate, full-time equivalent student enrollment is at least 25% Hispanic) is a factor in determining whether an institution is eligible for federal grants, contracts, or benefits to expand educational opportunities and improve the educational attainment of Hispanic students based on the Title V program under the Higher Education Act (also known as the Developing Hispanic-Serving Institutions Program). Institutions participating in this federal program are called "Hispanic-Serving Institutions," a term used by many scholars in this field. For additional information, see https://www2.ed.gov/about/offices/list/ope/idues/hsidivision.html (accessed 15 May 2017) and Núñez et al. (2015).

[5] In addition to HHE, other MSIs defined by the proportion of students enrolled in them are Asian-serving; American Indian-serving; other minority-serving; and non-minority serving. For more detail on all these categories, see Li 2007.

[6] See NSF/NCSES 2017a, Table 5-8, Table 5-9, and Table 5-10 for additional details.

[7] For the 2015 National Survey of College Graduates (NSCG), recent graduates include those who received their most recent degree in the 5 years between 1 July 2008 and 30 June 2013.

[8] Special tabulation from the 2015 NSCG.

[9] Special tabulation from the 2015 NSCG.

[10] Special tabulation from the 2015 Fall Enrollment survey in https://ncsesdata.nsf.gov/webcaspar/

[11] Special tabulation from the 2015 Fall Enrollment survey in https://ncsesdata.nsf.gov/webcaspar/

[12] In 2011–12, IPEDS began asking institutions whether they were exclusively a distance education institution (i.e., whether all their programs were offered via distance education, defined as "education that uses one or more technologies to deliver instruction to students who are separated from the instructor and to support regular and substantive interaction between the students and the instructor synchronously or asynchronously"). A distance education course is a course in which the instructional content is delivered exclusively via distance education. A distance education program is a program for which all the required coursework for program completion can be completed via distance education courses. Examinations, orientation, and practical experience components of courses or programs are not considered instructional content. For more details, see the IPEDS online glossary at https://nces.ed.gov/ipeds/glossary/.

[13] HarvardX and MITx are "collaborative institutional efforts between Harvard University and MIT to enhance campus-based education, advance educational research, and increase access to online learning opportunities worldwide" (Chuang and Ho 2016).

[14] FTE enrollments are derived from the "Enrollment by Race/Ethnicity" section of the IPEDS Fall Enrollment survey. The FTE of an institution's part-time enrollment is estimated by multiplying part-time enrollment by factors that vary by control and level of institution and level of student; the estimated FTE of part-time enrollment is then added to the institution's FTE. The Department of Education uses this formula to produce the FTE enrollment data published annually in the *Digest of Education Statistics*.

[15] For the definition of "net tuition revenue," see Glossary. Definitions of standard revenue and expenditure categories are available in the Delta Cost Project data dictionary, available at http://www.deltacostproject.org/delta-cost-project-database.

[16] Another large source of revenue for very high research institutions is "hospitals, independent operations, and other sources," which includes revenue generated by hospitals operated by the institution and revenues independent of or unrelated to instruction, research, or public services.

[17] Investment returns include realized and unrealized gains and losses. Institutions report the change in the value of their investment account, which is the reason behind the negative values under this category in Appendix Table 2-5. Thus, investment returns may not always represent revenue for the institution.

[18] In 2015, income from private and affiliated gifts, investment returns, and endowment income at private very high research institutions was about $66,700 per FTE compared with about $27,700 in income from net tuition and $25,700 in income from federal appropriations (Appendix Table 2-5).

[19] The 4-year and graduate institutions category includes the following 2010 Carnegie institution types: doctorate-granting universities—high research activity, doctoral/research universities, master's colleges and universities, and baccalaureate colleges. The data in this section correspond to the public institutions.

[20] Community colleges are the public "associate's colleges" in the 2010 Carnegie Classification of Institutions of Higher Education.

[21] Despite this variability in spending from year to year, as a percent of each year's total expenditures, instruction and all other spending streams remained relatively constant between 2000 and 2015 for not only community colleges but all institution types.

[22] The proportion of U.S.-trained doctorate holders employed at community colleges in adjunct positions grew from 12% in 1993 to 30% in 2015, according to estimates from the Survey of Doctorate Recipients. This suggests that one of the ways community colleges may have reined in expenses during this period was to increase their reliance on adjuncts.

[23] In this study, "low-income" referred to high school seniors whose families are in the bottom quartile of the income distribution. "High-achieving" referred to a student who scores at or above the 90th percentile on the ACT comprehensive or the SAT I (math and verbal) and whose high school grade point average is A- or higher. In this research, a "selective college" meant colleges and universities included in the categories from "Very Competitive Plus" to "Most Competitive" in Barron's *Profiles of American Colleges* (Hoxby and Avery 2013).

[24] These percentages include students whose financial aid package included student loans in combination with grants or other student aid, as well as those who only had student loans.

[25] Based on a special tabulation of the 2015 NSCG. A recent graduate is a respondent who received his or her most recent bachelor's degree between 1 July 2008 and 30 June 2013.

[26] In the case of public 4-year institutions, data were not available for the District of Columbia. In the case of private nonprofit 4-year or higher institutions, data were not available for Delaware, the District of Columbia, Hawaii, Idaho, Nevada, North Dakota, Utah, and Wyoming.

[27] Although the survey frame included new institutions during this period, the impact of the new institutions was very small and did not affect the overall trends. For additional information, see https://nsf.gov/statistics/2016/nsf16314/.

[28] The NSF/NCSES Survey of Graduate Students and Postdoctorates in Science and Engineering does not collect separate data for the master's and the doctoral level. For data on the primary source of financial support of doctorate recipients by broad field of study, see Appendix Table 2-14.

[29] Special tabulations from the Survey of Earned Doctorates.

[30] For the proportions corresponding to the 2003 Survey of Earned Doctorates please see Appendix Table NSB 2006 2-23 at https://nsf.gov/statistics/seind06/.

[31] Clinical psychology programs and programs that emphasize professional practice (professional schools and PsyD programs) are associated with higher debt, but even in the more research-focused subfields of psychology, lower percentages of doctorate recipients were debt free, and higher percentages had higher levels of debt, than those in other S&E fields. For information on debt levels of clinical versus nonclinical psychology doctorates in 1993–96, see *Psychology Doctorate Recipients: How Much Financial Debt at Graduation?* (NSF 00-321) at https://www.nsf.gov/statistics/issuebrf/sib00321.htm. Accessed 5 May 2017.

[32] Special tabulations from the Survey of Earned Doctorates.

Undergraduate Education, Enrollment, and Degrees in the United States

Undergraduate education in S&E courses prepares students majoring in S&E for the workforce. It also prepares nonmajors to become knowledgeable citizens with a basic understanding of science and mathematics concepts. This section includes indicators related to enrollment by type of institution, field, and demographic characteristics; intentions to major in S&E fields; and recent trends in the number of earned S&E degrees.

Undergraduate Enrollment in the United States

Overall Undergraduate Enrollment

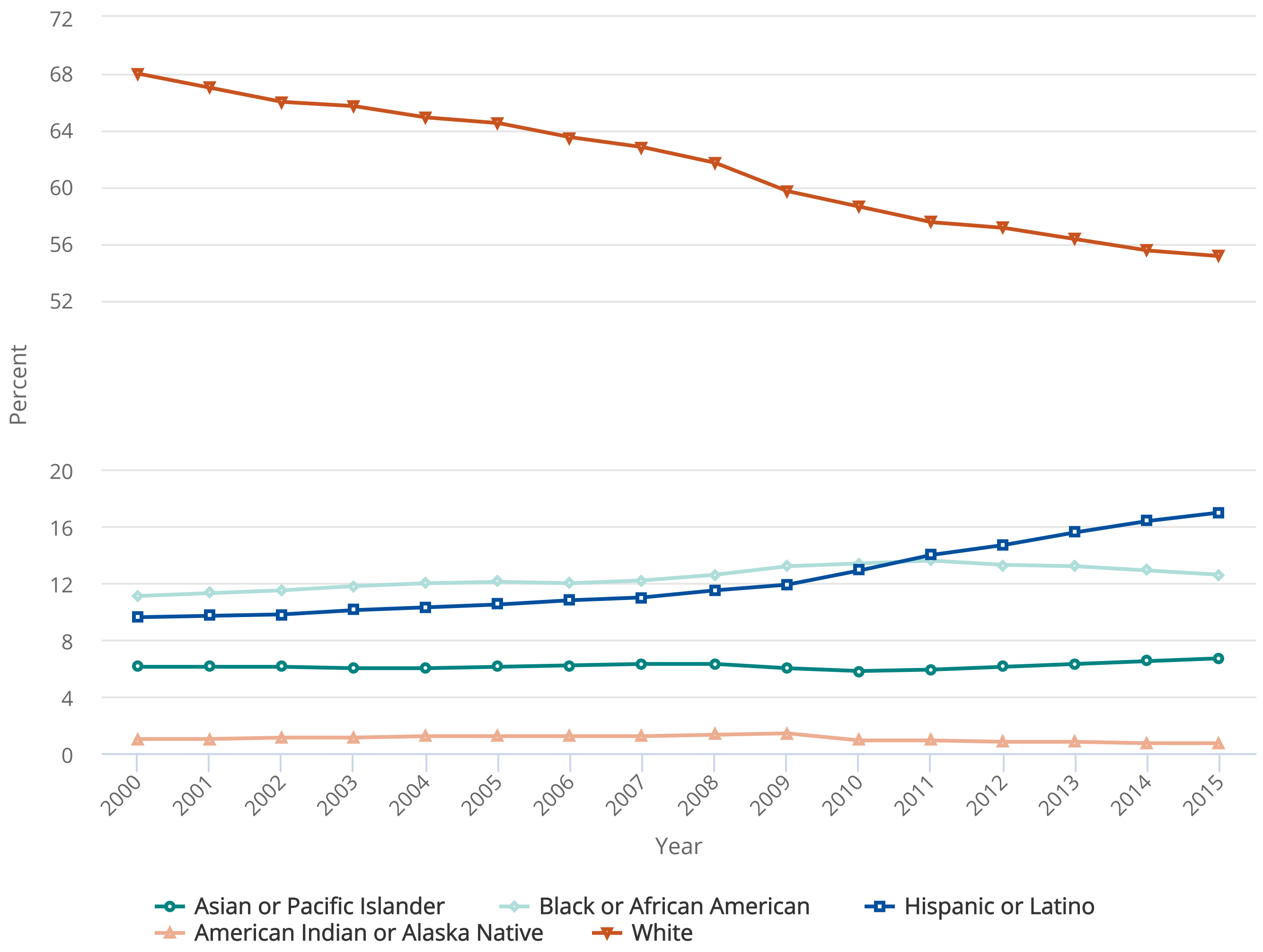
Enrollment in U.S. institutions of higher education at all levels rose from 15.5 million students in fall 2000 to more than 20.2 million in fall 2015, with two main periods of high growth—between 2000 and 2002 and between 2007 and 2010, following a pattern of rising enrollments when there are economic downturns. Undergraduate enrollment typically represents about 85% of all postsecondary enrollment (Appendix Table 2-5).

Undergraduate enrollment peaked at 18.3 million in 2010 but declined to 17.3 million in 2015, still about 30% higher than in 2000 (Appendix Table 2-5). As in previous years, the types of institutions enrolling the largest numbers of students at the undergraduate level in 2015 were associate's colleges (7.2 million, 42% of all undergraduates enrolled), master's colleges/universities (3.7 million, 21%), and doctorate-granting universities with very high research activity (2.1 million, 12%). Between 2000 and 2015, undergraduate enrollment increased consistently at most types of institutions (ranging between 22% and 35% at research universities, master's colleges, and baccalaureate colleges). (See sidebar Carnegie Classification of Academic Institutions for definitions of the types of academic institutions.)

Between 2000 and 2015, among U.S. citizens and permanent residents, the share of Hispanics and blacks enrolled full time in undergraduate programs increased (from 10% to 17% and from 11% to 13%, respectively); the shares of Asians and Pacific Islanders and of American Indians or Alaska Natives remained stable at about 6% and 1%, respectively; the share of whites declined (from 68% to 55%) (Figure 2-9). The most recent data show that about 3% of undergraduate students enrolled report being of more than one race. In general, enrollment is higher among black, Hispanic, and white women than among their male counterparts (special tabulation, IPEDS Fall Enrollment data; for additional data on undergraduate enrollment patterns by sex and race and ethnicity, see NSF/NCSES 2017a).[1]

FIGURE 2-9

Share of full-time undergraduate enrollment among U.S. citizens and permanent residents, by race and ethnicity: 2000–15



Note(s)

Hispanic may be any race. American Indian or Alaska Native, Asian or Pacific Islander, black or African American, and white refer to individuals who are not of Hispanic origin. Percentages do not add to total because data do not include individuals who did not report their race and ethnicity.

Source(s)

National Center for Education Statistics, Integrated Postsecondary Education Data System (IPEDS), Fall Enrollment Survey; National Science Foundation, National Center for Science and Engineering Statistics, WebCASPAR database, https://ncsesdata.nsf.gov/webcaspar/.

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According to the latest Census Bureau projections, increased enrollment in higher education is expected to come mainly from minority groups, particularly Hispanics (for details, see in *Science and Engineering Indicators 2016* Chapter 2 [2016] section Undergraduate Education Enrollment and Degrees in the United States [NSB 2016]). This increase may result in a larger number of academic institutions becoming high Hispanic enrollment and in considerable increases in the overall enrollment in community colleges, because nearly half of all Hispanic undergraduates are enrolled in community colleges.[2]

Undergraduate Enrollment in S&E

Freshmen Intentions to Major in S&E

The enrollment data presented in the previous section are not available by field of study because academic institutions vary in terms of when undergraduates declare a major, making it difficult to consistently measure enrollment by field. Since 1971, the annual The American Freshman: National Norms survey, administered by the Higher Education Research Institute at the University of California, Los Angeles, has asked freshmen at a large number of universities and colleges about their intended majors. Data show that in 2000, about one-third of all freshmen planned to study S&E; this proportion gradually rose to 45% by 2016 (Eagan et al. 2017). [3] Increases in the proportion of freshmen planning to major in biological and agricultural sciences and in engineering account for most of this growth. In 2016 about 45% of freshmen indicated they planned to major in an S&E field (up from about 8% in 2000); about 16% in the biological and agricultural sciences; 11% in engineering; 10% in the social and behavioral sciences; 6% in mathematics, statistics, or computer sciences; and 3% in the physical sciences.

International Undergraduate Enrollment

Based on recent data collected in the Student and Exchange Visitor Information System (SEVIS) at the Department of Homeland Security, international undergraduate enrollment increased consistently from nearly 350,000 in fall 2012 to nearly 451,000 in fall 2016 but dropped to about 441,000 by fall 2017 (Table 2-10).[4] ,[5] Between 2016 and 2017, international undergraduate enrollment in S&E fields remained steady, rising only 0.2% or 360 students, while declining 3.8% in non-S&E fields during this time. The decline may reflect a smaller influx of international students in the United States, a declining proportion of them staying in the United States than in the past, or a combination of these two factors.

In fall 2017, the top five countries sending S&E undergraduates to the United States were the same as in the previous year: China, Saudi Arabia, India, South Korea, and Kuwait (Appendix Table 2-16). Compared to fall 2016, the number of S&E undergraduates from China, India, and Kuwait enrolled in fall 2017 increased (by 3%, 11%, and 4% respectively) while the number from Saudi Arabia and South Korea declined (by 18% and 7% respectively).

At the undergraduate level, in 2017 40% of international students were enrolled in S&E fields (Table 2-10; Appendix Table 2-16). Within S&E, the broad fields with the highest enrollment of international students are engineering, computer sciences, and the social sciences (particularly economics). In the most recent academic year, the number of visa holders increased in computer sciences and mathematics (by 11% and 5% respectively). The largest declines in international student enrollment were in engineering and social sciences (5% and 3% respectively) and also in non-S&E (4%). In 2017, the proportion of undergraduate students enrolled in S&E fields was 50% or higher among students from Kuwait, Turkey, Malaysia, India, Nepal, and Pakistan, similar overall to previous years.

TABLE 2-10

International students enrolled in U.S. higher education institutions, by broad field and academic level: 2012–17

(Number)

Field and level	2012	2013	2014	2015	2016	2017
All fields						
All levels	633,070	673,480	747,400	776,720	840,160	808,640
Undergraduate	349,400	371,990	405,930	416,350	450,850	440,720
Graduate	283,680	301,490	341,470	360,380	389,310	367,920
S&E fields						
All levels	278,180	305,610	355,910	384,540	420,610	406,240
Undergraduate	115,800	130,050	147,790	157,820	176,570	176,930
Graduate	162,390	175,570	208,110	226,720	244,040	229,310
Non-S&E fields						
All levels	354,890	367,870	391,500	392,190	419,550	402,400
Undergraduate	233,600	241,950	258,140	258,520	274,280	263,790
Graduate	121,290	125,920	133,360	133,660	145,270	138,610

Note(s)

Data include active foreign national students on F-1 visas and exclude those on optional practical training. Undergraduate level includes associate's and bachelor's degrees; graduate level includes master's and doctoral degrees. Numbers are rounded to the nearest 10. Detail may not add to total because of rounding. Fall data include students who are in the SEVIS database between 16 April and 15 November of each year.

Source(s)

U.S. Department of Homeland Security, U.S. Immigration and Customs Enforcement, special tabulations (2017), Student and Exchange Visitor Information System (SEVIS) database.

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Engineering Enrollment

For the most part, U.S. undergraduates do not declare majors until their sophomore year, but engineering is an exception, generally requiring students to declare a major in their freshman year. Thus, engineering enrollment data compiled by the American Society for Engineering Education provides a glimpse into future undergraduate engineering degrees and student interest in the field (Yoder 2017). In the last 10 years, undergraduate engineering enrollment has been on the rise. The number of full-time undergraduate engineering students enrolled increased by 63% between 2006 and 2015, to about 610,000

(Appendix Table 2-17). Full-time freshman enrollment followed a similar pattern, peaking at 150,000 in 2015, the highest since 1982, indicating that interest in an engineering career is high.

Attainment and Retention in Undergraduate Education

One concern about the United States' ability to produce and retain talent in science and engineering is that students who start undergraduate programs in these fields do not complete them (President's Council of Advisors on Science and Technology 2012). Some drop out and do not complete any degree and others complete their degrees after switching to non–science, technology, engineering, and mathematics (STEM) majors. Degree attainment and retention are best measured by the Beginning Postsecondary Students (BPS) survey, which examined a nationally representative cohort of first-time, beginning students at the end of their first year in 2011–12, followed up with them 3 years later, and will contact them 6 years later.[6] Of the students surveyed in 2011–12, 43% enrolled in 2-year institutions, 53% enrolled in 4-year institutions, and 5% in less than 2-year institutions.[7] Overall, the data provide limited evidence that retention patterns vary across S&E and non-S&E fields of study.

Three years after enrolling in a 2-year institution in the 2011–12 academic year, about 55% of students had either completed an associate's degree (12%) or remained enrolled in school (at the same or another institution) without having earned a degree (43%); the remaining 45% were no longer enrolled at any institution and had not attained a degree (▦ Table 2-11). Overall, the level of degree attainment or continued enrollment did not vary much by students' declared major field of study. However, students who had been undecided about their major in 2011–12 were more likely to be no longer enrolled at any institution without having earned a degree by the spring of 2014: 55% of those with undecided majors were no longer enrolled compared to 43% of those with majors in the natural sciences and engineering, 40% of those in the social and behavioral sciences, and 45% of those in the non-S&E fields respectively.

In 4-year colleges and universities, 3 years after enrolling, the vast majority of students, were still enrolled either at their first institution or at another institution without having earned a credential (76%) or had attained an associate's or bachelor's degree (6%); about 18% had not earned a degree and were no longer enrolled at any institution. Overall those who had declared a major in S&E fields (natural sciences, engineering, and social and behavioral sciences) were slightly more likely to be enrolled 3 years later than students who had declared a non-S&E major (78% for natural sciences and engineering and 80% for social sciences compared to 74% for non-S&E majors). In addition, a higher proportion of students who declared a non-S&E major were somewhat more likely to be no longer enrolled at any institution (20%) than those who had declared a natural sciences and engineering (16%) or a social and behavioral sciences major (15%) (▦ Table 2-11).

TABLE 2-11

Retention and attainment of postsecondary students at the first academic institution attended through June 2014, by level of first institution and major field category: 2013–14

(Percent distribution)

Type of institution and major in 2011–12[a]	Number	Bachelor's	Associate's	No degree, still enrolled	No degree, left
2-year institutions					
All majors	1,697,800	s	12.1	43.4	44.5
Natural sciences and engineering[b]	224,600	s	13.3	44.0	42.7
Social and behavioral sciences	63,800	s	15.4	44.6	40.0
Non-S&E	1,283,000	s	12.3	43.2	44.5
Undecided	69,700	s	s	34.7	54.7
4-year institutions					
All majors	2,224,700	2.7	3.2	76.0	18.1
Natural sciences and engineering[b]	504,800	2.4	3.4	77.9	16.3
Social and behavioral sciences	227,200	2.8	2.0	80.3	14.9
Non-S&E	1,357,200	2.9	3.6	74.0	19.5
Undecided	117,900	s	s	85.2	12.8

s = suppressed for reasons of confidentiality and/or reliability.

[a] Refers to the first major declared by students.

[b] Includes engineering technologies and science technologies.

Note(s)

Percentages may not add to total because of rounding.

Source(s)

National Center for Education Statistics, 2011–12 Beginning Postsecondary Students Longitudinal Study First Follow-up (BPS:12/14).

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Field Switching

Among undergraduates who began postsecondary education in a 4-year institution, the majority who had declared a major during their first year in 2011–12 continued in the same major 3 years later. A larger proportion of students who declared a major in a non-S&E field (82%) than students who declared a natural sciences and engineering (69%) or social and behavioral sciences (67%) major remained in their field 3 years after beginning their postsecondary education (Table 2-12). Of the students who had not decided on a major in their first year, about equal proportions were enrolled in S&E (43%) or non-S&E (44%) fields 3 years later; the remainder continued to be undecided.

Although a greater proportion of students who started as S&E majors switched to a non-S&E field than the other way around, major switching resulted in a net increase in the number of S&E students. The absolute number of students switching into S&E fields is larger than those switching out because more than half of students start in non-S&E or undeclared majors (Table 2-12). Thus, the relatively small proportion of non-S&E students who later switch into S&E fields constitutes a larger number than the relatively large proportion of S&E students who switch out.

TABLE 2-12

Major switching among first-time postsecondary students beginning 4-year colleges and universities in 2011–12: 2013–14

(Percent distribution)

Major in 2011–12	Number	Major when last enrolled in 2013–14			
		Natural sciences and engineering	Social and behavioral sciences	Non-S&E	Undecided
All majors	2,237,000	21.8	12.2	60.4	5.6
Natural sciences and engineering	506,000	69.1	5.0	21.7	4.2
Social and behavioral sciences	229,100	5.1	67.3	24.3	3.3
Non-S&E	1,371,200	7.2	4.9	81.9	6.0
Undecided	118,400	21.8	21.0	44.3	12.9

Note(s)

Percentages may not add to total because of rounding.

Source(s)

National Center for Education Statistics, 2011–12 Beginning Postsecondary Students Longitudinal Study First Follow-up (BPS:12/14).

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Undergraduate Degree Awards

The number of undergraduate degrees awarded by U.S. academic institutions has been increasing over the past two decades in S&E and non-S&E fields. According to projections from the Department of Education, these trends are expected to continue at least through 2024 (Hussar and Bailey 2016).

S&E Associate's Degrees

Community colleges often are an important and relatively inexpensive gateway for students entering higher education. Associate's degrees, largely offered by 2-year programs at community colleges, are the terminal degree for some, but others continue their education at 4-year colleges or universities and subsequently earn higher degrees. About 19% of recent S&E

bachelor's degree holders—those who had earned their degree between academic years 2008–09 and 2012–13—had previously earned an associate's degree.[8] Many who transfer to baccalaureate-granting institutions do not earn associate's degrees before transferring; they may be able to transfer credit for specific courses.[9]

In 2015, 91,000 out of more than 1 million associate's degrees were in S&E fields (Appendix Table 2-18). S&E associate's degrees from all types of academic institutions declined between 2003 and 2007 but have been rising continuously since then. Until 2012, the overall trend mirrored the pattern of computer sciences, which account for a large portion of S&E associate's degrees and peaked in 2003, declined through 2007, and increased through 2012.[10] Between 2012 and 2015, the number of S&E associate's degrees continued to increase despite a decline in the number of associate's degrees awarded in computer sciences.

The number of associate's degrees in S&E technologies, not included in S&E degree totals because of their applied focus, grew by 72% since 2000. In 2015, about 144,000 associate's degrees were awarded in S&E technologies, down from 166,000 in 2012. Associate's degrees in these fields accounted for 14% of all associate's degrees in 2015; this proportion has ranged between 13% and 16% since 2000. Nearly three-quarters of the associate's degrees in S&E technologies are in health technologies, and close to one-quarter are in engineering technologies. The proportion of associate's degrees in engineering technologies, however, has declined from 48% of all S&E technologies degrees in 2000 to 24% in 2015 (or from 7% of all associate's degrees to 3%), whereas the proportion of associate's degrees in health technologies has increased from 50% in 2000 to 73% in 2013 (or from 7% of all associate's degrees to 10%).

S&E Associate's Degrees by Sex

Women earned 60% to 62% of all associate's degrees awarded between 2000 and 2015 (Appendix Table 2-18). The proportion of women earning S&E associate's degrees, however, declined from 48% in 2000 to 44% in 2015. Most of the decline is attributable to a decrease in women's share of computer sciences associate's degrees, which dropped continuously from 42% in 2000 to 21% in 2015.

S&E Associate's Degrees by Race and Ethnicity

Students from underrepresented minority groups (blacks, Hispanics, and American Indians and Alaska Natives) earn a higher proportion of associate's degrees than of bachelor's or more advanced degrees, in S&E fields and in all fields.[11] (See the S&E Bachelor's Degrees by Race and Ethnicity and S&E Doctoral Degrees by Race and Ethnicity sections.) In 2015, underrepresented minorities earned 35% of S&E associate's degrees—more than 40% of all associate's degrees in social and behavioral sciences; 39% of those in the biological sciences; about 30% of those in physical sciences, mathematics, and computer sciences; and 23% of those in engineering (Appendix Table 2-19).

S&E Associate's Degrees by Sex and Race and Ethnicity

In 2015, women earned more than half of the associate's degrees awarded to their respective racial or ethnic group in the social and behavioral sciences and in non-S&E fields, but less than half of those in the natural sciences and in engineering (Appendix Table 2-20). In all racial and ethnic groups, the difference was particularly large in engineering (between 56% and 80%, with the largest gap among blacks) and lower in the natural sciences (between 20% and 48%; with the largest gap among whites). In the last 15 years, the gender gap in the natural sciences grew in all racial and ethnic groups. During this period, the gender gap in engineering remained at similar levels among whites, Hispanics, and American Indians or Alaska Natives, but increased among blacks and declined among Asians or Pacific Islanders (for additional data, see NSF/NCSES 2017a).

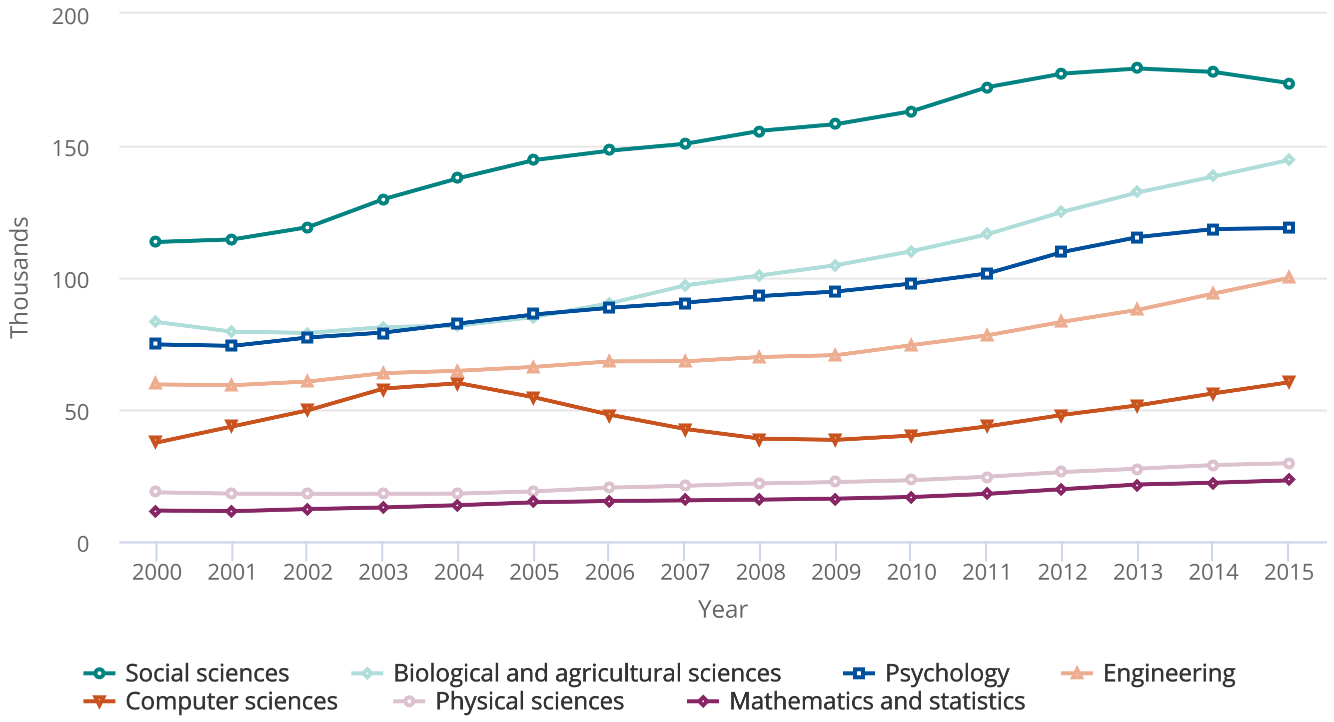
S&E Bachelor's Degrees

The baccalaureate is the most prevalent S&E degree, accounting for nearly 70% of all S&E degrees awarded. S&E bachelor's degrees have consistently accounted for roughly one-third of all bachelor's degrees for at least the past 15 years (Appendix Table 2-21). The number of S&E bachelor's degrees awarded rose steadily from about 400,000 in 2000 to more than 650,000 in

2015 (Appendix Table 2-21).[12] During this period, the number of bachelor's degrees awarded increased fairly consistently, although to different extents, in all S&E fields. The exception was computer sciences, where the number increased sharply from 2000 to 2004, dropped as sharply through 2009, but has been increasing again since then (Figure 2-10; Appendix Table 2-21).

FIGURE 2-10

S&E bachelor's degrees, by field: 2000–15



Note(s)

Physical sciences include earth, atmospheric, and ocean sciences.

Source(s)

National Center for Education Statistics, Integrated Postsecondary Education Data System (IPEDS), Completions Survey; National Science Foundation, National Center for Science and Engineering Statistics, WebCASPAR database, https://ncsesdata.nsf.gov/webcaspar/.

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S&E Bachelor's Degrees by Sex

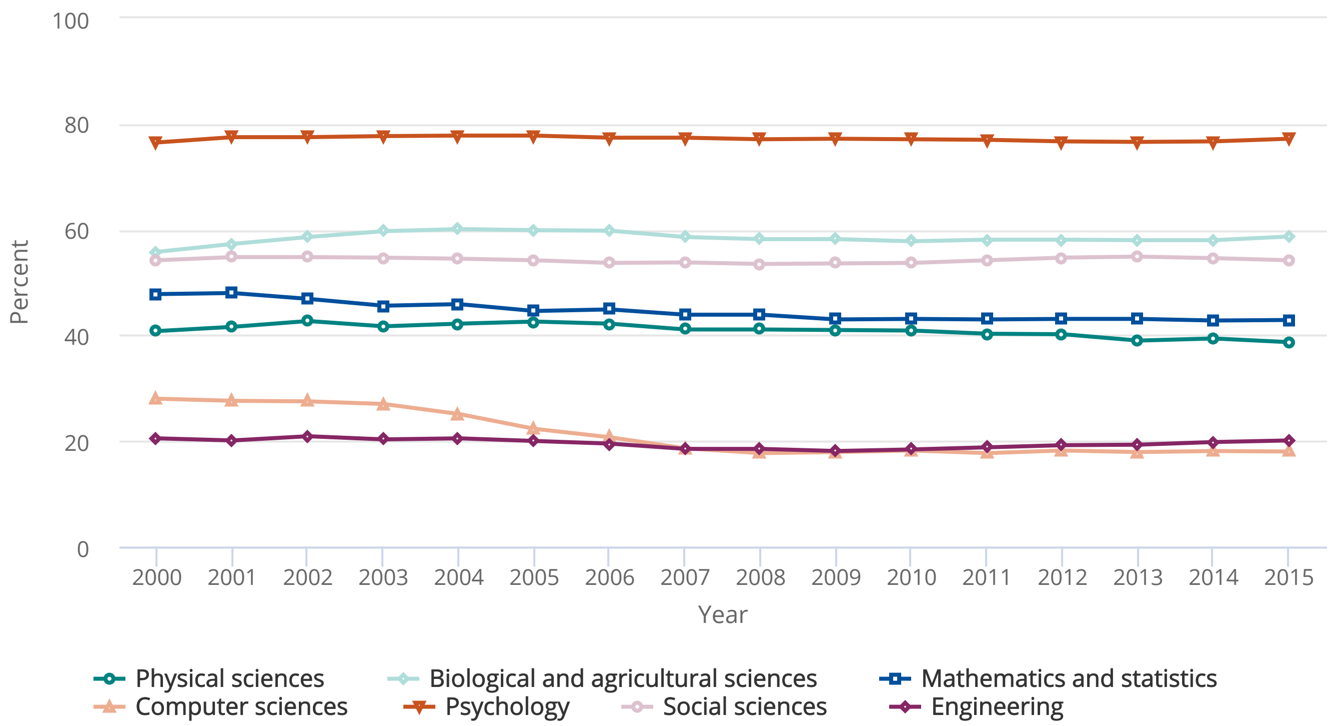
Since 1982, women have outnumbered men in undergraduate education. Since the late 1990s, they have earned about 57% of all bachelor's degrees and half of all S&E bachelor's degrees (NSF/NCSES 2017a).

Men and women prefer different fields of study; these tendencies continue at the master's and doctoral levels. In 2015, men earned the vast majority of bachelor's degrees awarded in engineering, computer sciences, and physics and more than half of the degrees in mathematics and statistics. Women earned half or more of the bachelor's degrees in psychology, biological sciences, agricultural sciences, and all the broad fields within social sciences except for economics (Appendix Table 2-21).

Since 2000, changes have not followed a consistent pattern. The share of bachelor's degrees awarded to women declined, particularly in computer sciences (by 10%) and in mathematics and statistics (by 5%) (Figure 2-11; Appendix Table 2-21). Agricultural sciences is the field in which the proportion of bachelor's degrees awarded to women grew the most during this period (by 9%) (Appendix Table 2-21).

FIGURE 2-11

Women's share of S&E bachelor's degrees, by field: 2000–15



Note(s)

Physical sciences include earth, atmospheric, and ocean sciences.

Source(s)

National Center for Education Statistics, Integrated Postsecondary Education Data System (IPEDS), Completions Survey; National Science Foundation, National Center for Science and Engineering Statistics, WebCASPAR database, https://ncsesdata.nsf.gov/webcaspar/.

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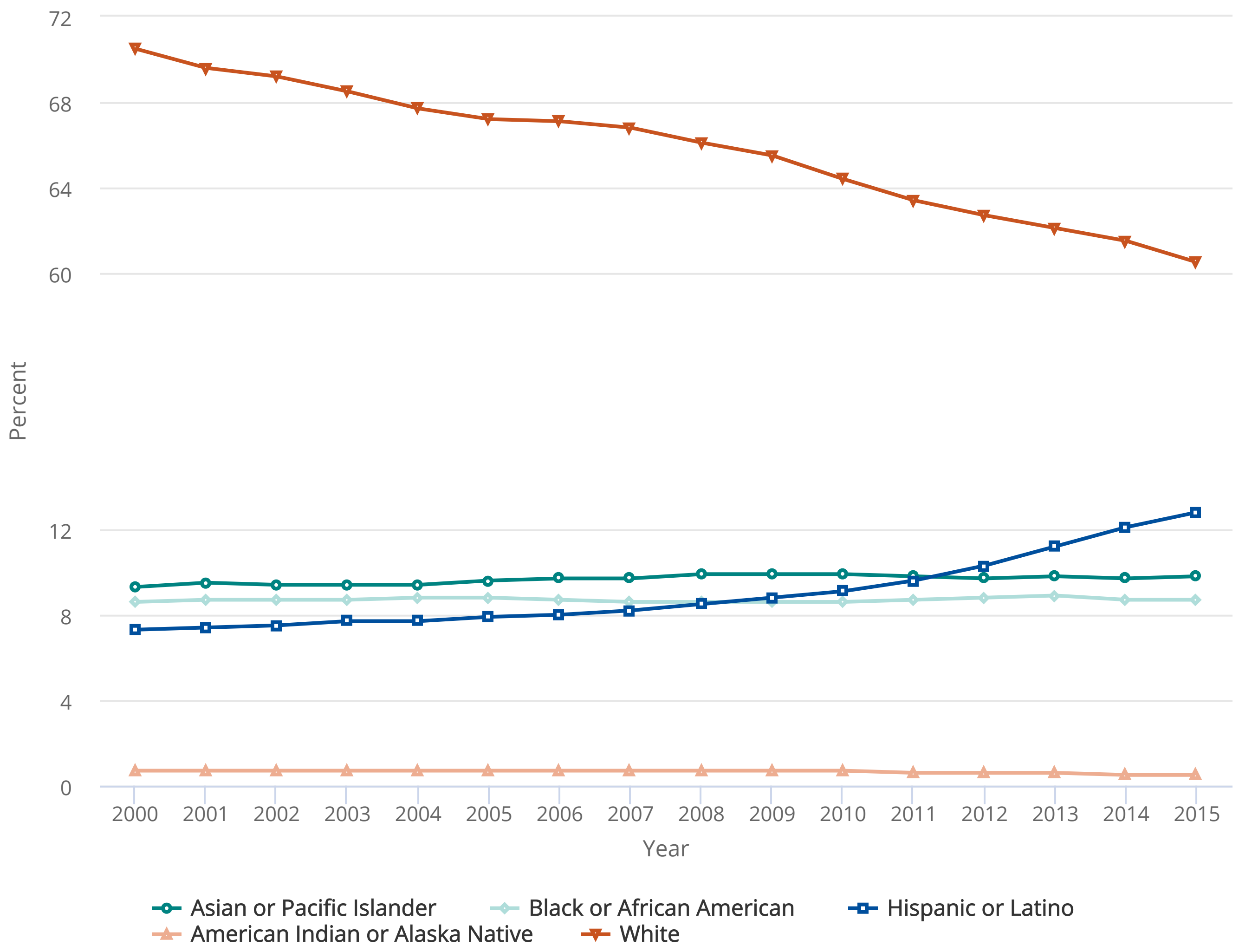
S&E Bachelor's Degrees by Race and Ethnicity

The racial and ethnic composition of the cohort of S&E bachelor's degree recipients has changed over time, reflecting population changes and increasing rates of college attendance by members of minority groups.[13]

Excluding temporary visa holders, between 2000 and 2015, the number of S&E bachelor's degrees earned by white students increased, but their share declined from 71% to 61% (Figure 2-12; Appendix Table 2-22). The share awarded to Hispanic students increased from 7% to 13%, and the share awarded to Asians increased from 9% to 10%. The share awarded to blacks (9%) has remained flat since 2000, and the share awarded to American Indians or Alaska Natives dropped from 0.7% to 0.5% in this period. The number of S&E bachelor's degrees earned by students of other or unknown race or ethnicity nearly doubled to about 27,000 in 2015 (about 4% of all S&E bachelor's degree recipients), suggesting that the specific percentages just cited are best viewed as approximations.

FIGURE 2-12

Share of S&E bachelor's degrees among U.S. citizens and permanent residents, by race and ethnicity: 2000–15



Note(s)

Hispanic may be any race. American Indian or Alaska Native, Asian or Pacific Islander, black or African American, and white refer to individuals who are not of Hispanic origin. Percentages do not add to 100% because data do not include individuals who did not report their race and ethnicity and those who reported two or more races.

Source(s)

National Center for Education Statistics, Integrated Postsecondary Education Data System (IPEDS), Completions Survey; National Science Foundation, National Center for Science and Engineering Statistics, WebCASPAR database, https://ncsesdata.nsf.gov/webcaspar/.

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Some of these trends may reflect changes in the way NCES and other federal statistical agencies began collecting race and ethnicity data under the Office of Management and Budget's most recent guidelines, which include students of multiple races starting with the data from the 2011 IPEDS Completions survey.[14] The new race and ethnicity categories now allow students who in the past may have reported their race or ethnicity to be American Indian or Alaska Native, Asian or Other Pacific Islander, black, Hispanic, or white, to be classified as a student of multiple races. As a result, this category reached about 20,000 bachelor's degree awards in 2015. However, because the trends discussed previously had also been observed before 2011, it is unlikely that the changes in the racial or ethnic categories contributed to the declines or increases to a very large extent.

Over more than three decades, the gap in educational attainment at the bachelor's level between young minorities and whites has narrowed but continues to be wide. From 1980 to 2015, the percentage of the population ages 25–29 with a bachelor's or higher degree in any field changed from 12% to 21% for blacks, 8% to 16% for Hispanics, and 25% to 43% for whites (NCES 2017). Their continuing differences with whites reflect lower rates of high school completion, college enrollment, and college persistence and attainment. (For information on immediate post–high school college enrollment rates, see Chapter 1 section Transition to Higher Education.)

Among those who did graduate from college in 2015, all groups but Asians and Pacific Islanders shared a similar distribution across broad S&E fields. Between 10% and 13% of all baccalaureate degrees were in the natural sciences, and 2%–5% were in in engineering. In contrast, Asians and Pacific Islanders were more likely than any of the other groups to earn degrees in the natural sciences (24%) and engineering fields (9%) (Appendix Table 2-22).

Since 2000, the total number of bachelor's degrees in all fields and in S&E fields overall increased for most racial and ethnic groups (Appendix Table 2-22). The exception was computer sciences. Degrees in this field increased considerably through 2003–04, sharply declined through 2008–09, then started to increase again, with degrees earned by Hispanics and whites exceeding their previous 2004 highs (57% higher for Hispanics, 6% higher for whites).[15]

S&E Bachelor's Degrees by Sex and Race and Ethnicity

In 2015, underrepresented minority women earned more than half of all S&E bachelor's degrees in their respective racial or ethnic groups, whereas white and Asian women earned close to half of them (Appendix Table 2-20). Women in all racial and ethnic groups earned the majority of bachelor's degrees in the social and behavioral sciences and in non-S&E fields, and about half of those in the natural sciences. In all racial and ethnic groups, the differences in the number of bachelor's degree awards between women and men is particularly high in engineering. Among underrepresented minority groups, gender gaps in engineering and the natural sciences became more pronounced between 2000 and 2015, particularly among blacks. The proportion of bachelor's degree awards in engineering to black women declined from 36% to 25% between 2000 and 2015; in the natural sciences, they declined from nearly 60% in 2000 to 52% in 2015 (for additional data by field of study, see NSF/NCSES 2017a).

S&E Bachelor's Degrees by Citizenship

Students on temporary visas in the United States have consistently earned a small share (about 4%–5%) of S&E degrees at the bachelor's level. In 2015, these students earned a substantially larger share of bachelor's degrees awarded in economics (17%); mathematics and statistics (14%); and in industrial, electrical, and chemical engineering (11%–13%). The total number of S&E bachelor's degrees awarded to students on temporary visas increased from about 15,000 in 2000 to about 19,000 in 2004, then declined to less than 17,000 by 2008, but it has increased continuously since then, peaking at almost 33,000 in 2015 (Appendix Table 2-22).

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[1] For the most recent nationally representative data on undergraduate student enrollment by disability status, see NSB 2016 and NSF/NCSES 2017a.

[2] Special tabulation from the IPEDS Fall Enrollment survey, available at https://ncsesdata.nsf.gov/webcaspar/.

[3] For details on freshmen intention to major in S&E by demographics, see NSB 2016.

[4]The data in this section include international students pursuing both bachelor's and associate's degrees. The data come from the Student and Exchange Visitor Information System (SEVIS). SEVIS collects administrative data, including the numbers of all international students enrolled in colleges and universities in the United States. Data include students who are in the SEVIS database between April 16 and November 15 of each year.

[5] The data include active foreign national students on F-1 visas in the SEVIS database, excluding those participating in optional practical training (OPT). Students with F visas have the option of working in the United States by engaging in OPT, temporary employment directly related to the student's major area of study, during or after completion of the degree program. Students can apply for 12 months of OPT at each level of education. Starting in 2008, students in certain STEM fields became eligible for an additional 17 months of OPT. The number of students in OPT varies according to labor market conditions.

[6] See https://nces.ed.gov/surveys/bps/about.asp. Accessed 8 May 2017.

[7] Special tabulation from the Beginning Postsecondary Student survey.

[8] Based on a special tabulation of the 2015 NSCG. A recent graduate is a respondent who received his or her most recent degree between 1 July 2008 and 30 June 2013.

[9] Some credentials in the form of certificates take up to a year to complete. Recent research on licenses and certification from the Census Bureau's Survey of Income and Program Participation shows that the vast majority of these types of credentials are in health care, education, and trades; business/finance management; legal/social services; and other non-S&E fields. Only 2% of the licenses and certifications are in S&E, specifically in computer sciences (Ewert and Kominski 2014).

[10] Data on degree completion from NCES were obtained from WebCASPAR (https://webcaspar.nsf.gov/). Data uploaded in WebCASPAR correspond to NCES provisional data, which undergo all NCES data quality control procedures and are imputed for nonresponding institutions. These data are used by NCES in its First Look (Provisional Data) publications.

[11] Data for racial and ethnic groups are for U.S. citizens and permanent residents only.

[12] Data on degree completion from NCES were obtained from WebCASPAR (https://webcaspar.nsf.gov/). Data uploaded in WebCASPAR correspond to NCES provisional data, which undergo all NCES data quality control procedures and are imputed for nonresponding institutions. These data are used by NCES in its First Look (Provisional Data) publications.

[13] Data for racial and ethnic groups are for U.S. citizens and permanent residents only.

[14] For details on the changes in the race and ethnicity categories in IPEDS, see https://nces.ed.gov/ipeds/Section/ana_Changes_to_25_2007_169. Accessed 21 August 2017.

[15] For patterns on S&E bachelor's degrees awarded to minority men and minority women, see NSF/NCSES 2017a.

Graduate Education, Enrollment, and Degrees in the United States

Graduate education in S&E contributes to a country's global competitiveness by producing the highly skilled workers of the future and the research needed for a knowledge-based economy. This section includes indicators related to S&E graduate enrollment and degree awards in the United States including participation by women, minorities, and international students in U.S. graduate education.

Graduate Enrollment by Field

S&E graduate enrollment in the United States reached nearly 668,000 in 2015, an increase of about 35% since 2000 (Appendix Table 2-23).[1] Most of the growth in this period occurred in the 2000s, with stable enrollment between 2008 and 2013 and resumed growth in 2014 and 2015. The highest enrollment growth was recorded in computer sciences, mathematics and statistics, medical sciences, and engineering. Most other S&E fields also had substantial growth. Enrollment in the social sciences grew from 83,000 in 2000 to 111,000 in 2011, then declined to 103,000 by 2015.

Enrollment in computer sciences had increased gradually or remained stable through 2012, then accelerated from 52,000 to more than 86,000 in only 3 years. Temporary visa students accounted for most of this growth (Appendix Table 2-23). Along the same lines, the number of first-time, full-time graduate students in computer sciences, an indicator of developing trends, nearly doubled in the last 3 years (Appendix Table 2-24).

In 2015, first-time, full-time graduate enrollees accounted for 24% of total S&E graduate enrollment. These students are typically pursuing a master's or a doctoral degree right after or within about a year after earning their undergraduate degree. This indicator can be sensitive to economic conditions; for example, high unemployment tends to lead to an increase in first-time, full-time graduate enrollment. Between 2000 and 2015, first-time, full-time graduate S&E enrollment has increased fairly steadily in most broad S&E fields while peaking in engineering, computer sciences, mathematics and statistics, agricultural, and biological sciences. In psychology and in the social sciences, the number of first-time, full-time graduate students had declined slightly in recent years but the numbers in these two broad fields increased in 2015 (Appendix Table 2-24).[2]

Graduate Enrollment of International Students

Since 2008, S&E graduate students with temporary visas have kept U.S. graduate enrollment in these fields from shrinking. Since that year, these students' share has risen from 26% to 36% of the total, making them an ever more vital part of this critical enterprise. Although enrollment of international students in S&E fields has been on the rise, graduate enrollment of U.S. citizens and permanent residents declined between 2008 and 2013 but slowly started growing again in 2014 (Appendix Table 2-25). In 2015, about 240,000 international students on temporary visas were enrolled in S&E graduate programs, representing 36% of total U.S. graduate enrollment. The proportion of international enrollment was highest—47% or higher—in computer sciences, engineering (particularly high in electrical engineering), mathematics and statistics, and economics.[3]

After a post-9/11 decline, the numbers of first-time, full-time international graduate students enrolled increased steadily in most broad fields through 2015 (Appendix Table 2-24). Declines and subsequent increases in number were concentrated in engineering and computer sciences, the fields heavily favored by international students. Between 2000 and 2015, the proportion of first-time, full-time S&E international students increased, particularly in computer sciences and mathematics and statistics.

Most recently, data from SEVIS show an overall 6% decline in international graduate students from fall 2016 to fall 2017 (▦ Table 2-10; Appendix Table 2-26).[4] As stated previously, this decline may reflect a smaller influx of international students in the United States, and given the way these data are collected, it may also reflect a smaller portion of international students staying in the United States to pursue another degree.[5] In 2017, 62% of all international students in graduate programs at U.S. institutions were enrolled in S&E fields. Between fall 2016 and fall 2017, the number of international graduate students enrolled in S&E fields decreased most in computer sciences (from 70,600 to 61,500) and engineering (from 96,300 to 89,000). The number of international students enrolled in mathematics increased (from 15,800 to 18,100) and remained at fairly similar levels in other S&E fields.

The top sending locations in 2017 continued to be India and China, accounting for 69% of the international S&E graduate students in the United States, followed by Iran, South Korea, Saudi Arabia, and Taiwan (Appendix Table 2-26). Compared to 2016, the number of graduate S&E students from India, Saudi Arabia, Iran, and South Korea declined in 2017 (by 19%, 11%, 1%, and 1% respectively) while the number from China and Taiwan increased (by 4% and 5% respectively).

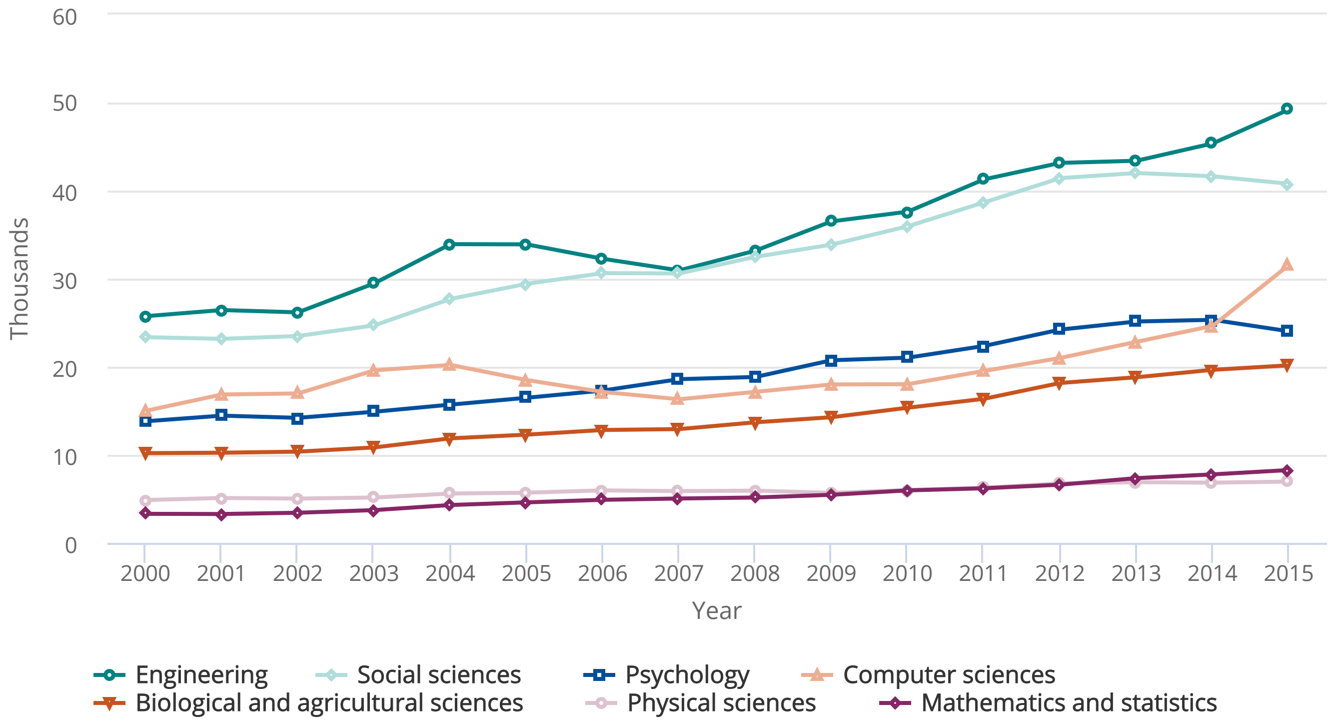
About 8 in 10 graduate students from India, Iran, Bangladesh, and Sri Lanka and more than 6 in 10 of graduate students from China, Pakistan, and Nepal were enrolled in an S&E field. In the case of Iran, more than half of them were enrolled in engineering; in the case of Bangladesh, 42%. In contrast, more than 60% of the international students from Canada, South Korea, Brazil and Japan were enrolled in non-S&E fields.

S&E Master's Degrees

In some fields, such as engineering and geosciences, a master's degree can fully prepare students for an established career track. In other fields, master's degrees primarily mark a step toward doctoral degrees. Master's degrees awarded in S&E fields nearly doubled from about 96,000 in 2000 to about 181,000 in 2015 (Appendix Table 2-27).[6] Increases occurred in all major science fields and were strongest in mathematics and statistics, biological sciences, computer sciences, and engineering (Appendix Table 2-27). In computer sciences and engineering, the number of master's degrees awarded declined between 2004 and 2007, similar to bachelor's degrees, but it has since increased and in 2015 was the highest in the last 16 years (📊Figure 2-13).

FIGURE 2-13

S&E master's degrees, by field: 2000–15



Note(s)

Physical sciences include earth, atmospheric, and ocean sciences.

Source(s)

National Center for Education Statistics, Integrated Postsecondary Education Data System (IPEDS), Completions Survey; National Science Foundation, National Center for Science and Engineering Statistics, WebCASPAR database, https://ncsesdata.nsf.gov/webcaspar/.

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Professional Science Master's (PSM) programs, which stress interdisciplinary training, are a relatively new direction in graduate education. PSM degrees provide advanced training in an S&E field beyond the bachelor's degree level while also developing administrative and business skills that are valued by employers, such as leadership, project management, teamwork, and communication (for details on PSM degrees, see NSB 2014:2–30). As of January 2017, there were 355 PSM programs within 165 institutions; the most popular PSM programs were in the fields of biotechnology, biomedical, and pharmaceuticals; environmental science, ocean science, sustainability, and geographic information systems; and computer sciences, analytics, and big data or statistics (PSM 2017).

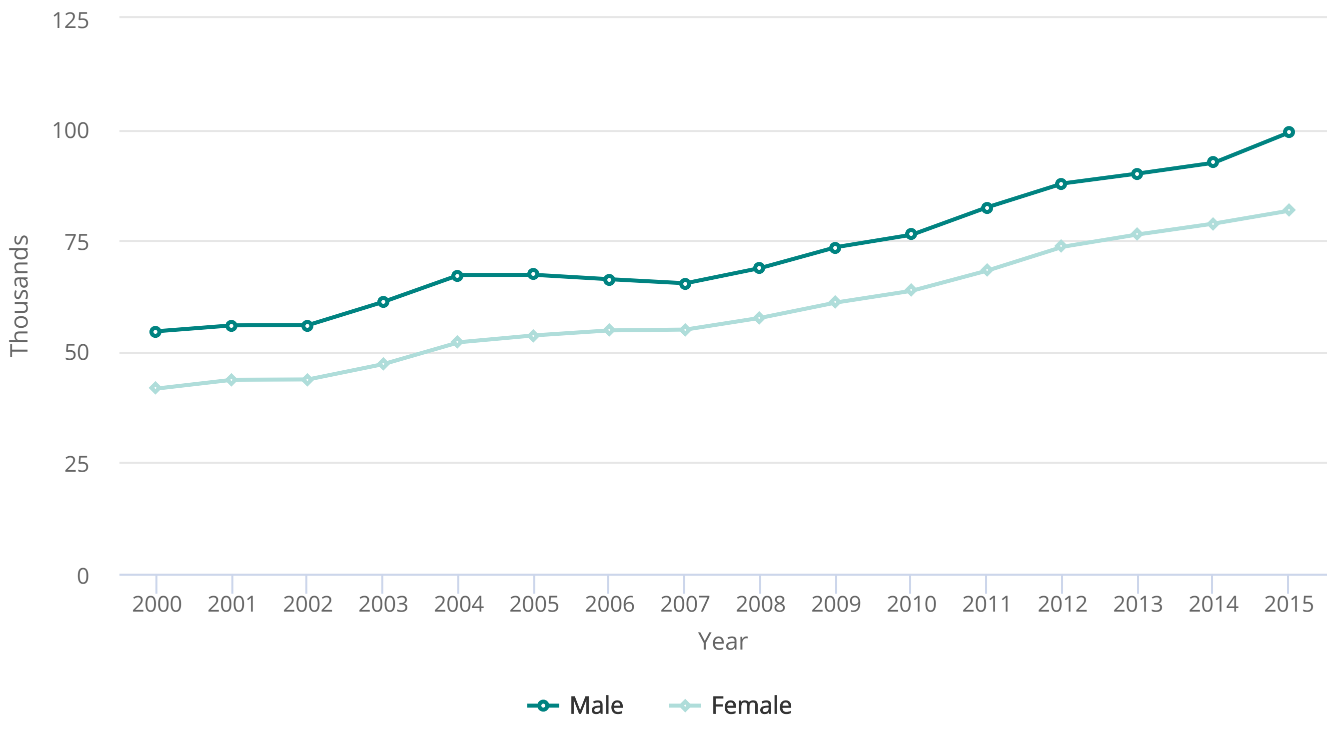
S&E Master's Degrees by Sex

The number of S&E master's degrees earned by men and women rose between 2000 and 2015 (Figure 2-14). In 2000, women earned 43% of all S&E master's degrees; by 2015, they earned 45% (Appendix Table 2-27). Among U.S. citizens and permanent residents, women earned half of all S&E master's degrees (NSF/NCSES 2017a).

Women's share of S&E master's degrees varies widely by field. As with bachelor's degrees, in 2015, women earned a majority of master's degrees in psychology, biological sciences, agricultural sciences, and most social sciences except economics, but lower proportions of master's degrees in engineering, computer sciences, and physics. Between 2000 and 2015, the proportion of master's degrees earned by women increased in engineering (21% to 24%), economics (38% to 41%), and physics (20% to 23%), but declined in computer sciences (33% to 31%) (Appendix Table 2-27).

FIGURE 2-14

S&E master's degrees, by sex of recipient: 2000–15



Source(s)

National Center for Education Statistics, Integrated Postsecondary Education Data System (IPEDS), Completions Survey; National Science Foundation, National Center for Science and Engineering Statistics, WebCASPAR database, https://ncsesdata.nsf.gov/webcaspar/.

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S&E Master's Degrees by Race and Ethnicity

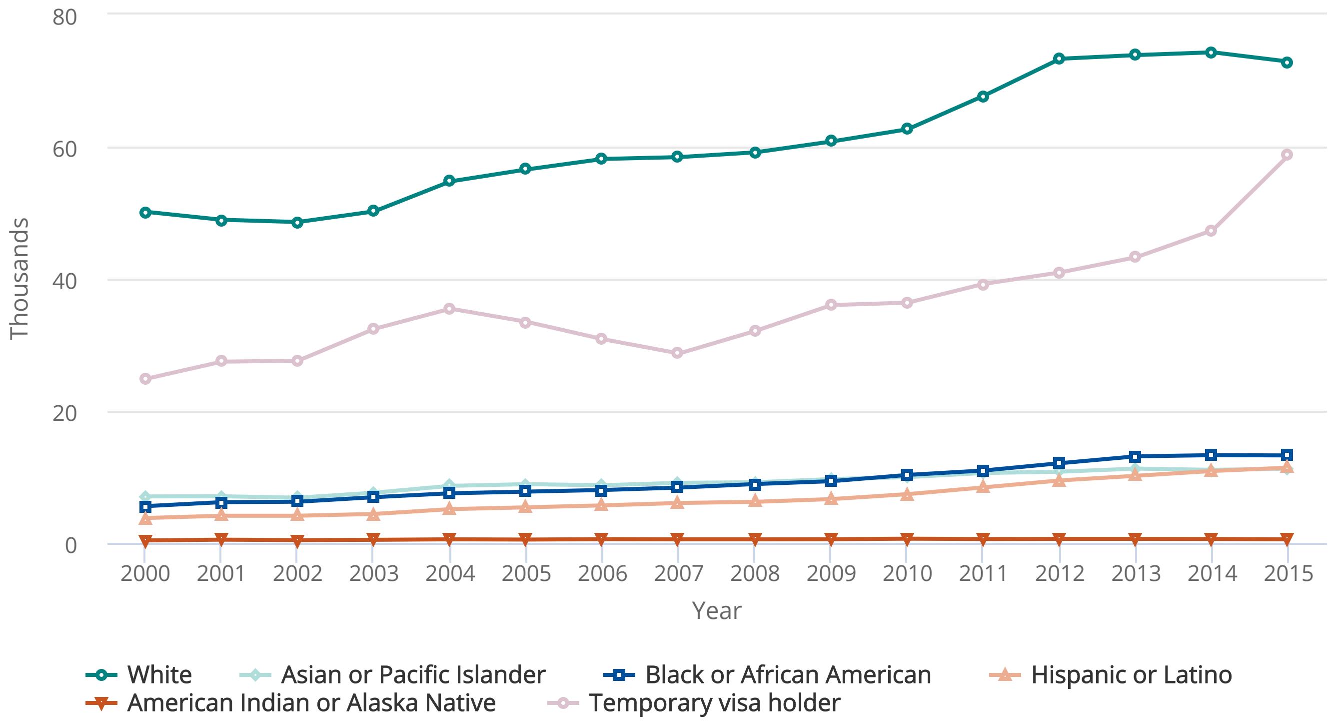
The number of S&E master's degrees awarded to U.S. citizens and permanent residents increased for all racial and ethnic groups between 2000 and 2015 (📊 Figure 2-15; Appendix Table 2-28).[7] The number of S&E master's degrees earned by underrepresented minorities (25,200) is less than half the number earned by temporary visa holders (59,000).

The proportion of U.S. S&E master's degrees earned by underrepresented racial and ethnic minorities increased from 14% to 21% between 2000 and 2015; the proportion earned by whites fell from 70% to 60%. The trends are similar to those found in the data on bachelor's degree awards among racial and ethnic groups. Blacks accounted for 11% of S&E master's degree recipients in 2015, up from 8% in 2000; Hispanics accounted for 9%, up from 5%; and American Indians and Alaska Natives accounted for 0.4%, similar to the proportion in 2000. The proportion of Asian and Pacific Islander S&E recipients declined from 10% to 9% in this period.

Some of the changes by race and ethnicity over time may reflect changes in the way NCES and other federal statistical agencies collect information on this topic. Beginning in 2011, some students may be classified as multiracial who in the past may have been reported as American Indian or Alaska Native, Asian and Pacific Islander, black, Hispanic, or white. The number of students with a multiracial identity accounted for about 13,000 master's degree awards in 2015. However, because the trends by race and ethnicity discussed here had also been observed before 2011, it is unlikely that the changes in the racial or ethnic categories contributed to the declines or increases to a very large extent.

FIGURE 2-15

S&E master's degrees, by race, ethnicity, and citizenship: 2000–15



Note(s)

Data on race and ethnicity include U.S. citizens and permanent residents. Hispanic may be any race. American Indian or Alaska Native, Asian or Pacific Islander, black or African American, and white refer to individuals who are not of Hispanic origin.

Source(s)

National Center for Education Statistics, Integrated Postsecondary Education Data System (IPEDS), Completions Survey; National Science Foundation, National Center for Science and Engineering Statistics, WebCASPAR database, https://ncsesdata.nsf.gov/webcaspar/.

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S&E Master's Degrees by Sex and Race and Ethnicity

In 2015, women earned more than half of the master's degrees awarded to their respective racial or ethnic group in the social and behavioral sciences and in non-S&E fields but less than half of those in the natural sciences and engineering. Between 2000 and 2015, the proportion of natural sciences and engineering master's degrees awarded to women rose among American Indians or Alaska Natives, declined among blacks, and remained relatively stable among Hispanics (Appendix Table 2-20). (For additional details by field, see NSF/NCSES 2017a.)

S&E Master's Degrees by Citizenship

In 2015, 59,000 international students earned an S&E master's degree in the United States, up from nearly 25,000 in 2000. International students make up a much higher proportion of S&E master's degree recipients than of bachelor's or associate's degree recipients, but they make up a smaller proportion of S&E doctoral degrees. In 2015, international students earned 35% of S&E master's degrees, up from 26% in 2000. Their degrees were heavily concentrated in computer sciences, economics, mathematics and statistics, and engineering, where they received about half or more of all master's degrees awarded in 2015 (Appendix Table 2-28). Within engineering, students on temporary visas earned 70% of the master's degrees awarded in electrical engineering and more than half of the master's degrees in chemical and materials engineering.

In 2015, the number of S&E master's degrees awarded to students on temporary visas reached its highest point in recent years (59,000), after a sharp decline between 2004 and 2007. Most of the drop during this period was accounted for by decreasing numbers of temporary visa holders in the computer sciences and engineering fields, but in both fields, numbers rebounded by more than 50% in the following years.

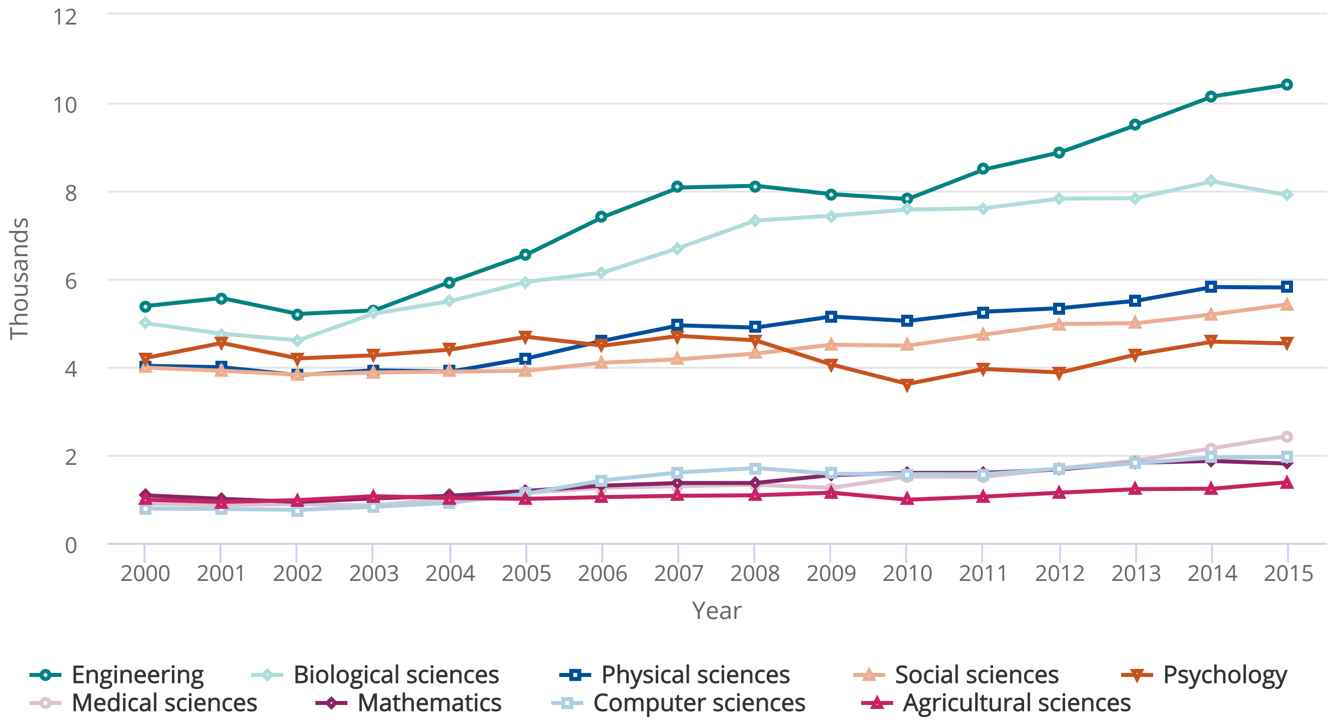
S&E Doctoral Degrees

Doctoral education in the United States generates new knowledge by closely linking specialized education and hands-on research experience. The results are important for the society as a whole and for U.S. competitiveness in a global knowledge-based economy, as they prepare a new generation of researchers and a highly skilled workforce for various sectors of the economy including academia, industry, government, and nonprofit organizations. Decades-long participation of large and growing numbers of temporary visa holders attests to the attractiveness of U.S. doctoral education.

The number of S&E doctorates conferred annually by U.S. universities increased from nearly 28,000 in 2000 to 45,000 in 2015 (Appendix Table 2-29). U.S. citizens and permanent residents as well as temporary visa holders contributed to this growth (for a discussion on international doctoral recipients who stay in the United States after obtaining their degree, see Chapter 3).[8] The largest increases in S&E doctorates between 2000 and 2015 were in engineering and computer sciences (Figure 2-16).[9]

FIGURE 2-16

S&E doctoral degrees earned in U.S. universities, by field: 2000–15



Note(s)

Physical sciences include earth, atmospheric, and ocean sciences. Data differ from doctoral degree data in other tables and figures in this report that are based on the National Science Foundation Survey of Earned Doctorates and that refer to research doctorates only. Greatest differences are in psychology and medical sciences.

Source(s)

National Center for Education Statistics, Integrated Postsecondary Education Data System (IPEDS), Completions Survey; National Science Foundation, National Center for Science and Engineering Statistics, WebCASPAR database, https://ncsesdata.nsf.gov/webcaspar/.

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Time to Doctoral Degree Completion

The time required to earn a doctoral degree and the success rates of those entering doctoral programs are important for those pursuing a degree, the universities awarding the degree, and the agencies and organizations funding doctoral study. Longer times to degree mean lost earnings and a higher risk of attrition. Median time to degree (as measured by time from graduate school entry to doctorate receipt) increased through the mid-1990s but has since decreased in all S&E fields from 7.7 to 6.8 years (Appendix Table 2-30). The physical sciences and mathematics had the shortest time to degree, whereas the social sciences and medical and other health sciences had the longest.

Time to degree varied among institution types (see sidebar 💬 Carnegie Classification of Academic Institutions) and was typically longer at universities that were less strongly oriented toward research (▦ Table 2-13). Consequently, time to degree was shortest at research universities with very high research activity (6.7 years in 2015, down from 7.2 years in 2000). Doctorate recipients at medical schools also finished relatively quickly (6.7 years in 2015).

The median time to degree varies by demographic groups, but these variations reflect differences among broad fields of study. In 2015, across all doctorate recipients, women had a longer time to degree than men (7.7 versus 7.2 years, respectively) (Appendix Table 2-31). However, with few exceptions, these differences were very small when comparing men and women within broad S&E fields. In engineering, women took slightly less time than men (6.3 versus 6.7 years, respectively), and in medical and other health sciences, the difference reversed and was considerably larger (9.7 for women versus 7.7 years for men).

In most natural sciences and engineering fields, time to degree was longer for temporary visa holders than for U.S. students, particularly in the physical sciences (6.7 versus 5.7 years, respectively). However, in the medical and other health sciences, as in computer sciences, temporary visa holders finished faster. Among U.S. citizen and permanent resident students, in most broad S&E fields, median time to degree was shorter for whites than for other groups.

TABLE 2-13

Median number of years from entering graduate school to receipt of S&E doctorate, by 2010 Carnegie classification of doctorate-granting institution: 2000–15

(Median number of years)

Year	All institutions	Research universities — very high research activity	Research universities — high research activity	Doctoral/ research universities	Medical schools and medical centers	Other or not classified
2000	7.5	7.2	8.2	9.2	7.2	7.9
2001	7.2	7.2	8.2	9.7	6.9	7.7
2002	7.5	7.2	8.1	9.9	6.9	8.2
2003	7.6	7.2	8.2	9.7	6.9	9.0
2004	7.2	7.0	8.0	9.3	6.9	7.7
2005	7.3	7.2	7.9	9.4	7.0	8.2
2006	7.2	7.0	7.9	9.0	6.9	7.7
2007	7.0	7.0	7.7	8.9	6.9	7.7
2008	7.0	6.9	7.7	8.9	6.7	7.7
2009	7.0	6.9	7.7	9.2	6.8	7.7
2010	7.0	6.9	7.7	8.9	6.7	7.3
2011	7.0	6.9	7.7	8.8	6.7	7.7
2012	7.0	6.8	7.7	8.9	6.7	7.9
2013	6.9	6.7	7.4	9.3	6.7	7.7
2014	6.9	6.7	7.3	9.4	6.7	7.7
2015	6.8	6.7	7.3	9.4	6.7	7.7

Note(s)

Includes only doctorate recipients who reported year of entry to first graduate school or program.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2016), 2015 Survey of Earned Doctorates (SED).

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S&E Doctoral Degrees by Sex

Women have reached parity among S&E doctoral degree recipients: among U.S. citizens and permanent residents, women's proportion of S&E doctoral degrees was 51% in 2015, up from 45% in 2000 (Appendix Table 2-29). During this period, women made gains in most major fields, among continuing disparities in other fields. In 2015, women earned half or more of doctorates in non-S&E fields, in most social and behavioral sciences except for economics, in the biological sciences, and in the medical and other health sciences. They earned less than one-third of the doctorates awarded in mathematics and statistics, computer sciences, and engineering (Appendix Table 2-29). Although low, the proportions of degrees earned by women in these fields and the physical sciences (particularly in physics) were higher than they were in 2000.

Between 2000 and 2015, the number of S&E doctorates earned by women grew faster (from nearly 11,000 to nearly 20,000) than the number earned by men (from almost 17,000 to 24,000), increasing women's proportion of S&E doctoral degrees during this period (Appendix Table 2-29). The increase among women occurred in most major S&E fields. For example, the number of engineering doctorates earned by U.S. women more than doubled from approximately 500 in 2000 to nearly 1,200 in 2015. Similar growth patterns occurred in women's biological sciences doctorates from 1,700 to 3,000, and in physical sciences doctorates from 600 to nearly 1,000.

S&E Doctoral Degrees by Disability Status

In 2014, 7% of S&E doctorate recipients reported having a disability; they were fairly similar to those who did not report a disability in terms of broad field of study. Nearly half of the S&E doctorate recipients who reported one or more disabilities of any type indicated that they had visual disabilities, 40% reported cognitive disabilities, 18% reported hearing disabilities, 10% reported lifting disabilities, and 6% reported walking disabilities (NSF/NCSES 2017a).

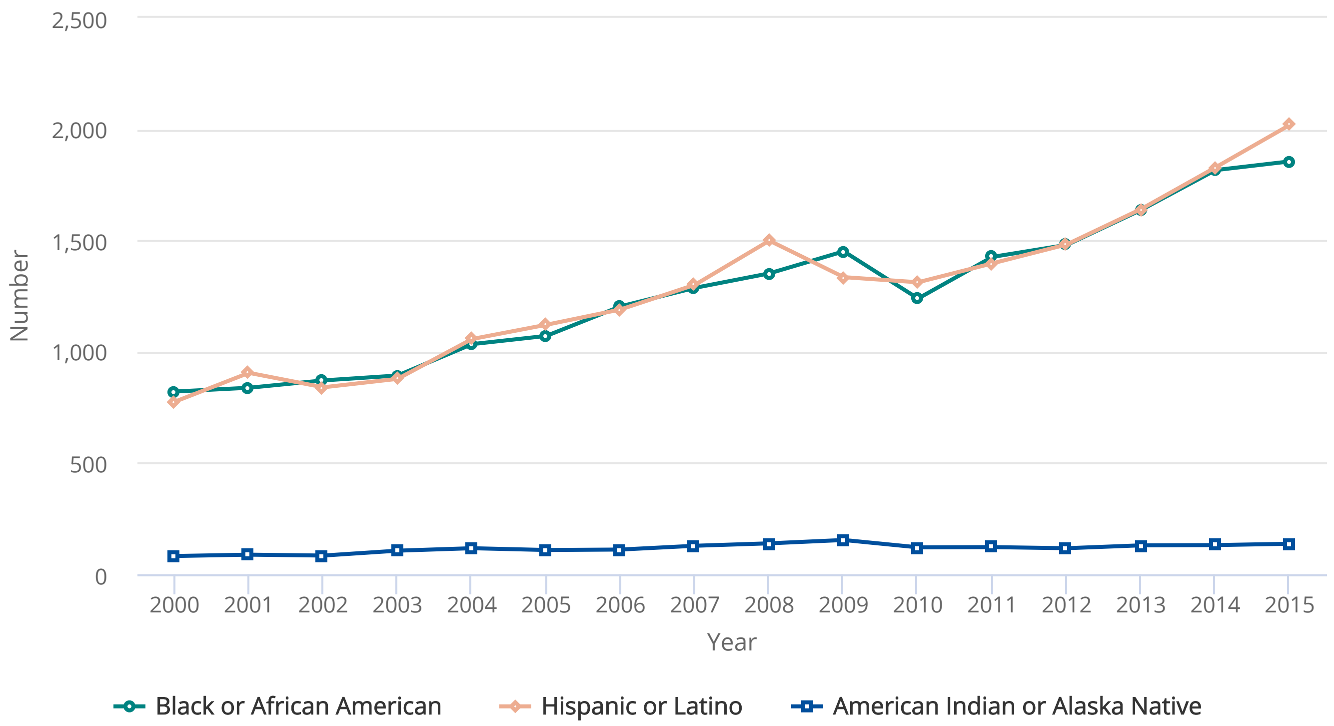
S&E Doctoral Degrees by Race and Ethnicity

The number and the proportion of doctoral degrees in S&E fields earned by underrepresented minorities increased between 2000 and 2015. In 2015, blacks earned 1,855 S&E doctorates, Hispanics earned 2,019, and American Indians and Alaska Natives earned 137—altogether accounting for 9% of all S&E doctoral degrees awarded that year, up from 6% in 2000 (Appendix Table 2-32).[10] The share of the S&E doctorates earned by U.S. citizen and permanent resident underrepresented minority doctorate recipients rose from 9% to 14% in the same period. Gains by all groups contributed to this rise, although blacks and Hispanics saw larger gains than American Indians or Alaska Natives (Figure 2-17). Asians and Pacific Islanders (citizens and permanent residents) earned 6% of all S&E doctorates in 2015, similar to 2000. Although whites (including U.S. citizens and permanent residents) saw a rise in the number of S&E doctorates (Figure 2-18), their share of all U.S. S&E doctorates fell from 54% in 2000 to 44% in 2015 (Appendix Table 2-32).

Some of the changes by race and ethnicity over time may reflect changes in the way NCES and other federal statistical agencies collect information on this topic. Beginning in 2011, some students may be classified as multiracial who in the past may have been reported as American Indian or Alaska Native, Asian and Pacific Islander, black, Hispanic, or white. The number of students with a multiracial identity accounted for about 500 doctoral degree awards in 2015. However, because the trends by race and ethnicity discussed here had also been observed before 2011, it is unlikely that the changes in the racial or ethnic categories contributed to the declines or increases to a very large extent.

FIGURE 2-17

S&E doctoral degrees earned by U.S. citizen and permanent resident underrepresented minorities, by race and ethnicity: 2000–15



Note(s)

Data differ from doctoral degree data in other tables and figures in this report that are based on the National Science Foundation Survey of Earned Doctorates and that refer to research doctorates only. Greatest differences are in psychology and medical or other health sciences. Hispanic may be any race. American Indian or Alaska Native and black or African American refer to individuals who are not of Hispanic origin. The large drop in 2009 is due to the change in doctoral categories in the survey.

Source(s)

National Center for Education Statistics, Integrated Postsecondary Education Data System (IPEDS), Completions Survey; National Science Foundation, National Center for Science and Engineering Statistics, WebCASPAR database, https://ncsesdata.nsf.gov/webcaspar/.

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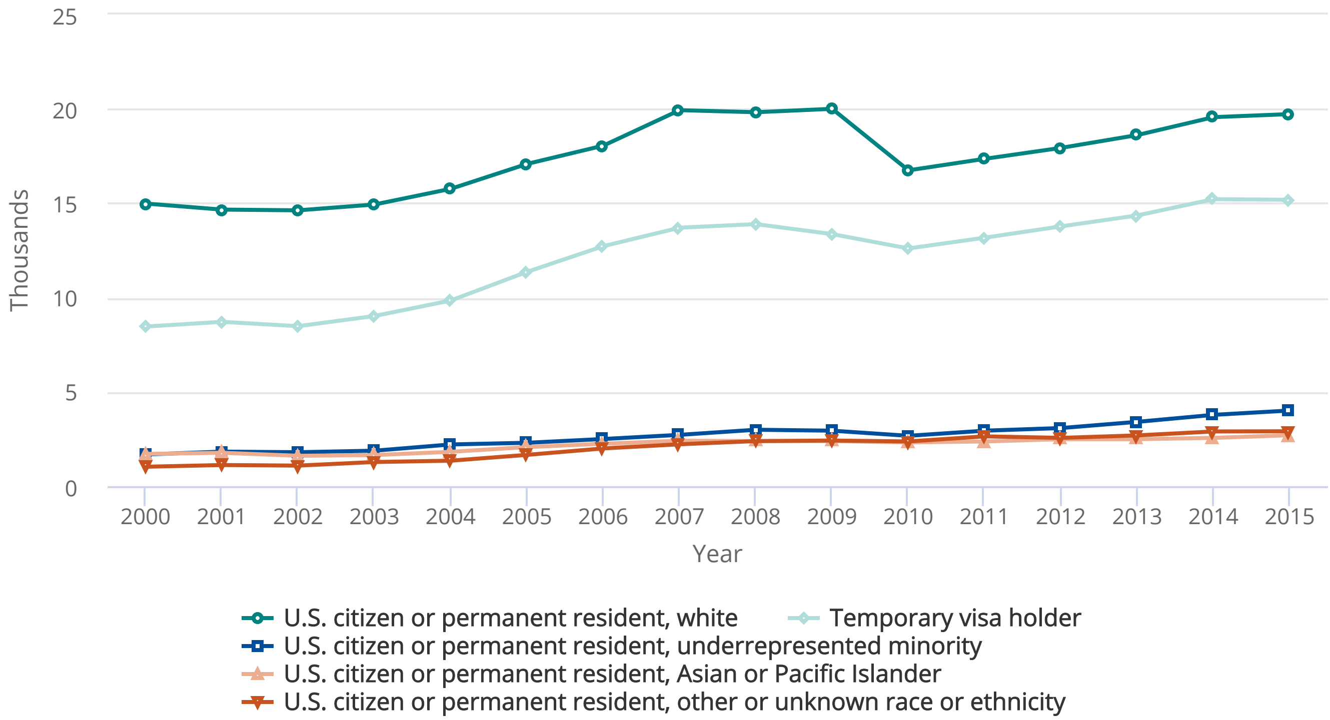
FIGURE 2-18

S&E doctoral degrees, by race, ethnicity, and citizenship: 2000–15



Note(s)

Minority includes American Indian or Alaska Native, Asian or Pacific Islander, black or African American, and Hispanic or Latino. Data differ from doctoral degree data in other tables and figures in this report that are based on the National Science Foundation Survey of Earned Doctorates and that refer to research doctorates only. Greatest differences are in psychology and medical or other health sciences. The large drop in U.S. data in 2009 is due to the change in doctoral categories in the survey.

Source(s)

National Center for Education Statistics, Integrated Postsecondary Education Data System (IPEDS), Completions Survey; National Science Foundation, National Center for Science and Engineering Statistics, WebCASPAR database, https://ncsesdata.nsf.gov/webcaspar/.

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S&E Doctoral Degrees by Sex and Race and Ethnicity

In 2015, women earned half or more of the doctoral degrees awarded to their respective racial or ethnic groups in the natural sciences, the social and behavioral sciences, and in non-S&E fields. Since 2000, the proportion of women earning doctorates increased in the natural sciences, social and behavioral sciences, and engineering in all racial and ethnic groups except for American Indians or Alaska Natives (Appendix Table 2-20). (For additional data by field of study, see NSF/NCSES 2017a.)

International S&E Doctorate Recipients

International students on temporary visas earned more than 15,000 S&E doctorates in 2015, up from about 8,000 in 2000, with a rising share from 30% to 34% over the period. In engineering, they earned more than half of the degrees in any subspecialty; the same for mathematics and computer sciences and for economics (Appendix Table 2-34). They earned relatively lower proportions of doctoral degrees in some S&E fields—for example, 28% in biological sciences, 20% in medical sciences, 6% in psychology, and between 12% and 22% in most social sciences except economics (Appendix Table 2-34).

Countries and Economies of Origin

Since 1995, U.S. universities have awarded a total of almost 221,000 S&E doctorates to temporary visa holders. Over that period, the top 10 countries and economies of origin accounted for 70% of all international recipients of these degrees (▦Table 2-14). Six out of those top 10 locations are in Asia.

TABLE 2-14

Recipients of U.S. S&E doctorates on temporary visas, by country or economy of origin: 1995–2015

(Number and percent)

Country or economy	Number	Percent
All recipients on temporary visas	220,684	100.0
Top 10 total	155,259	70.4
China[a]	63,576	28.8
India	30,251	13.7
South Korea	20,626	9.3
Taiwan	13,001	5.9
Turkey	6,610	3.0
Canada	6,350	2.9
Thailand	4,564	2.1
Mexico	3,502	1.6
Japan	3,473	1.6
Iran	3,306	1.5
All others	65,425	29.6

[a] Includes Hong Kong.

Note(s)

Data include non-U.S. citizens with unknown visa status.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2016), 2015 Survey of Earned Doctorates (SED).

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Asia

From 1995 to 2015, students from four Asian locations (China, India, South Korea, and Taiwan, in descending order) earned more than half of all U.S. S&E doctoral degrees awarded to international students (127,000 of 221,000)—nearly five times the number of doctoral recipients from Europe (26,000). China accounted for more than one-quarter of all these international S&E doctorates (64,000), followed by India (30,000), South Korea (21,000), and Taiwan (13,000). Most of these degrees were awarded in engineering, biological sciences, and physical sciences (Table 2-15). A larger proportion of South Korean and Taiwanese students (exceeding 25%) than Chinese and Indian (approaching 10%) earned a doctorate in a non-S&E field.

The number of S&E doctorates earned by students from China has increased more than seven times in the last 20 years, from 675 to nearly 5,000, whereas the numbers from India nearly tripled between 2002 and 2009 but have since remained stable at 2,100. In the last 10 years, the numbers of S&E doctorates from South Korea and Taiwan have been broadly stable but remain low (about 900 and 500, respectively) (Figure 2-19).

TABLE 2-15

Asian recipients of U.S. S&E doctorates on temporary visas, by field and country or economy of origin: 1995–2015

(Number)

Field	Asia	China[a]	India	South Korea	Taiwan
All fields	166,920	68,379	32,737	26,630	16,619
S&E	146,258	63,576	30,251	20,626	13,001
Engineering	55,215	23,101	13,208	8,274	5,045
Science	91,043	40,475	17,043	12,352	7,956
Agricultural sciences	4,927	1,745	823	720	441
Biological sciences	25,149	12,202	5,654	2,459	2,374
Computer sciences	9,287	4,229	2,477	1,015	597
Earth, atmospheric, and ocean sciences	2,803	1,563	357	338	228
Mathematics	7,494	4,493	805	967	503
Medical and other health sciences	5,298	1,368	1,371	672	878
Physical sciences	20,528	10,816	3,516	2,216	1,305
Psychology	2,053	530	277	481	320
Social sciences	13,504	3,529	1,763	3,484	1,310
Non-S&E	20,662	4,803	2,486	6,004	3,618

[a] Includes Hong Kong.

Note(s)

Asia includes Afghanistan, Bangladesh, Bhutan, Brunei, Burma, Cambodia, China, Christmas Island, Hong Kong, India, Indonesia, Japan, Kazakhstan, Kyrgyzstan, Laos, Macau, Malaysia, Maldives, Mongolia, Nepal, North Korea, Pakistan, Papua New Guinea, Paracel Islands, Philippines, Singapore, South Korea, Spratly Islands, Sri Lanka, Taiwan, Tajikistan, Thailand, Timor-Leste, Turkmenistan, Uzbekistan, and Vietnam. Data include temporary visa holders and non-U.S. citizens with unknown visa status.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2016), 2015 Survey of Earned Doctorates (SED).

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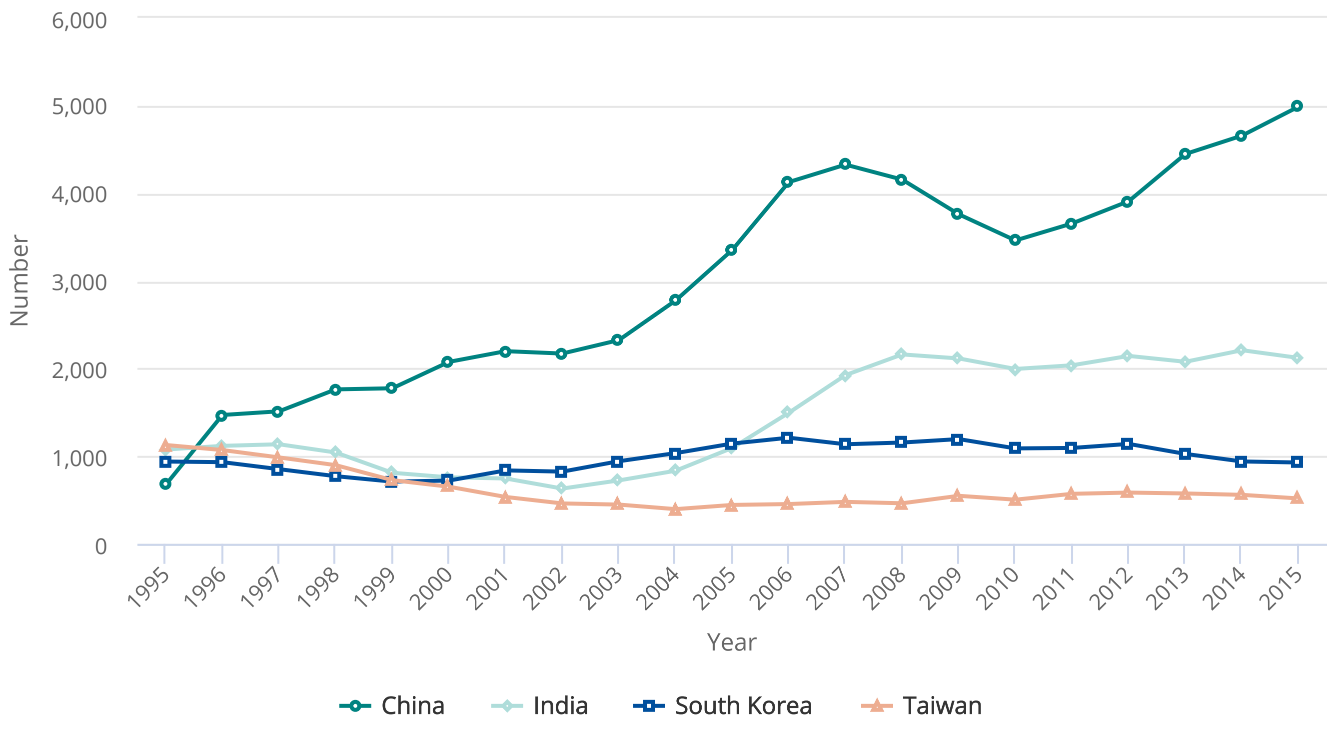
FIGURE 2-19

U.S. S&E doctoral degree recipients, by selected Asian country or economy of origin: 1995–2015



Note(s)

Degree recipients include temporary visa holders and non-U.S. citizens with unknown visa status. Data for China include Hong Kong.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2016), 2015 Survey of Earned Doctorates (SED).

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Europe

European students earned far fewer U.S. S&E doctorates than Asian students between 1995 and 2015, and they tended to focus less on engineering than did their Asian counterparts (Table 2-15 and Table 2-16). European countries whose students earned the largest number of U.S. S&E doctorates from 1995 to 2015 were Turkey, Germany, Russia, Italy, Romania, Greece, and France, in that order. Trends in doctorate recipients from individual Western European countries vary widely (Figure 2-20). The number of Central and Eastern European students earning S&E doctorates at U.S. universities nearly doubled between 1995 and 2007, but it has declined since then; the number of doctorate recipients from Western Europe and Scandinavia has been more stable overall (Figure 2-21). A higher proportion of doctorate recipients from Russia, Romania, Greece, and Turkey than from France, Italy, and Germany earned their doctorates in S&E. Russian and Romanian doctorate recipients were more likely than those from Western European countries to earn their doctorates in mathematics and physical sciences, and Turkish, Greek, and French doctorate recipients were more likely to earn doctoral degrees in engineering (▦ Table 2-16).

TABLE 2-16 ▦

European recipients of U.S. S&E doctorates on temporary visas, by field and region or country of origin: 1995–2015

(Number)

Field	All European countries	Turkey	Germany	Russia	Italy	Romania	Greece	France
All fields	40,056	7,850	4,164	3,216	2,706	2,225	2,147	2,212
S&E	32,591	6,610	3,252	2,882	2,101	1,967	1,896	1,778
Engineering	8,059	2,894	546	427	489	317	674	589
Science	24,532	3,716	2,706	2,455	1,612	1,650	1,222	1,189
Agricultural sciences	874	243	95	18	54	21	50	53
Biological sciences	4,396	566	509	401	206	225	211	245
Computer sciences	2,093	421	196	134	98	257	247	66
Earth, atmospheric, and ocean sciences	1,081	89	159	100	90	39	27	98
Mathematics	2,927	328	269	365	191	358	132	78
Medical and other health sciences	612	49	84	15	23	18	50	30
Physical sciences	5,851	647	613	1,027	341	508	266	332
Psychology	882	134	145	44	42	37	39	20
Social sciences	5,816	1,239	636	351	567	187	200	267
Non-S&E	7,465	1,240	912	334	605	258	251	434

Note(s)

Data include temporary visa holders and non-U.S. citizens with unknown visa status.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2016), 2015 Survey of Earned Doctorates (SED).

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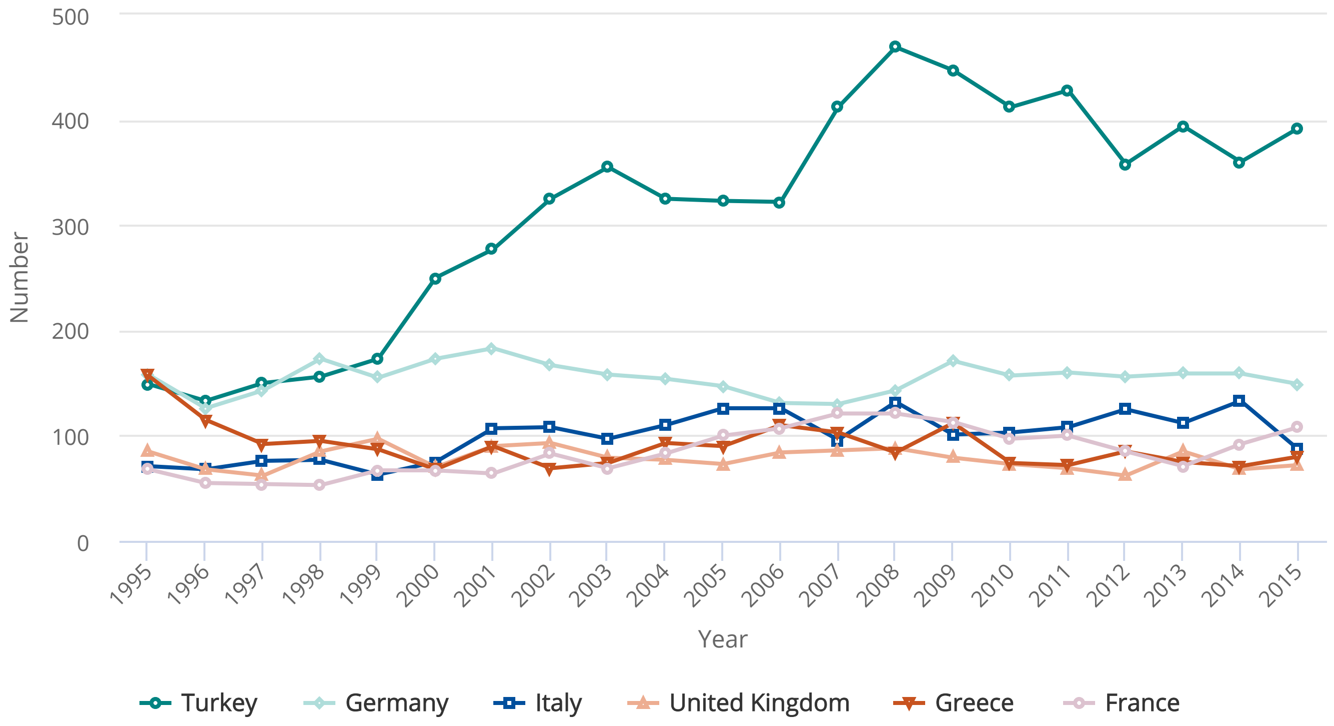
FIGURE 2-20

U.S. S&E doctoral degree recipients, by selected European country: 1995–2015



Note(s)

Degree recipients include temporary visa holders and non-U.S. citizens with unknown visa status.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2016), 2015 Survey of Earned Doctorates (SED).

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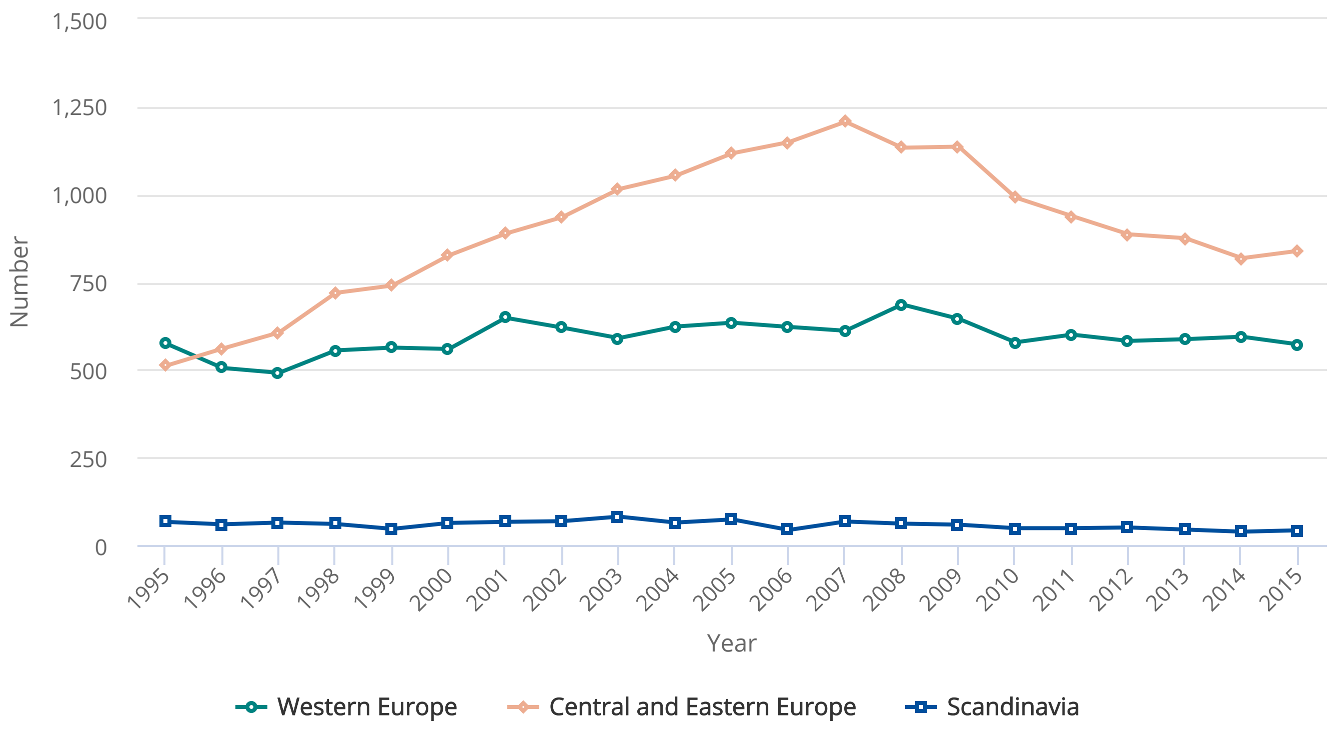
FIGURE 2-21

U.S. S&E doctoral degree recipients from Europe, by region: 1995–2015



Note(s)

Degree recipients include temporary visa holders and non-U.S. citizens with unknown visa status. Western Europe includes Andorra, Austria, Belgium, France, Gibraltar, Germany, Holy See (Vatican City), Ireland, Italy, Liechtenstein, Luxembourg, Malta, Monaco, Netherlands, Portugal, San Marino, Spain, Switzerland, and United Kingdom. Central and Eastern Europe includes Albania, Belarus, Bosnia-Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Greece, Hungary, Kosovo, Latvia, Lithuania, Macedonia, Moldova, Montenegro, Poland, Romania, Russia, Serbia, Slovakia, Slovenia, Turkey, and Ukraine. Scandinavia includes Denmark, Finland, Iceland, Norway, and Sweden. Data are not comparable with data presented in earlier years because a slightly different geographic taxonomy was used.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2016), 2015 Survey of Earned Doctorates (SED).

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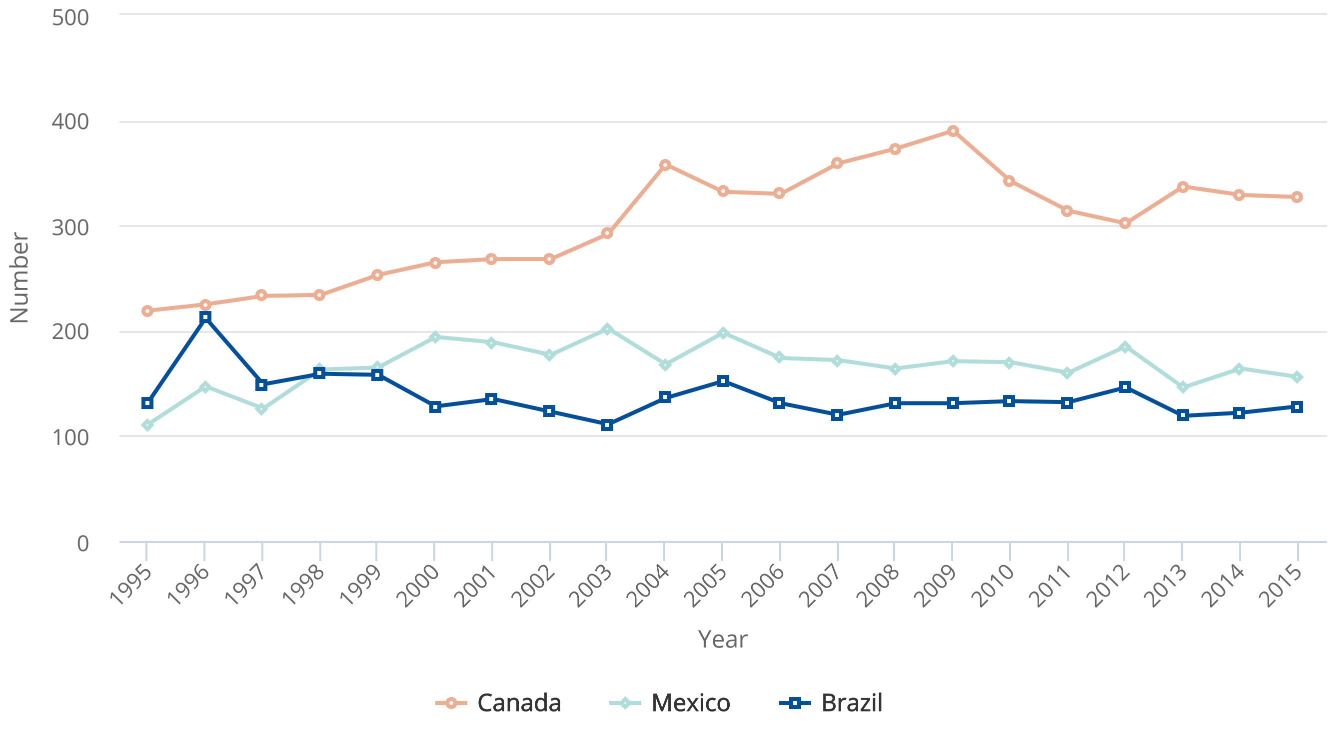
The Americas

Despite the proximity of Canada and Mexico to the United States, the shares of U.S. S&E doctoral degrees awarded to residents of these countries were small compared with those awarded to students from Asia and Europe. The number of U.S. S&E doctoral degrees earned by students from Canada increased from about 219 in 1995 to 390 in 2009, but it has overall declined in the last 6 years. The overall numbers of doctoral degree recipients from Mexico and Brazil peaked earlier (2003 and 1996, respectively) and have been relatively stable in recent years (Figure 2-22).

A higher proportion of Mexican and Brazilian students earned U.S. doctorates in S&E fields than the comparable proportion for Canadians (Table 2-17); this pattern was particularly strong in engineering and agricultural sciences.

FIGURE 2-22

U.S. S&E doctoral degree recipients from Canada, Mexico, and Brazil: 1995–2015



Note(s)

Degree recipients include temporary visa holders and non-U.S. citizens with unknown visa status.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2016), 2015 Survey of Earned Doctorates (SED).

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TABLE 2-17

North American, South American, and Middle Eastern recipients of U.S. S&E doctorates on temporary visas, by field and region and country of origin: 1995–2015

(Number)

Field	North and South America[a]				Middle East[b]			
	All countries	Canada	Mexico	Brazil	All countries	Iran	Jordan	Saudi Arabia
All fields	25,338	9,194	4,103	3,457	11,444	3,434	1,872	1,800
S&E	19,796	6,350	3,502	2,888	9,388	3,306	1,624	1,302
Engineering	4,241	1,023	887	625	4,486	2,347	693	487
Science	15,555	5,327	2,615	2,263	4,902	959	931	815
Agricultural sciences	1,860	211	522	392	285	42	78	59
Biological sciences	3,647	1,333	509	504	916	177	170	114
Computer sciences	720	228	124	167	635	186	118	120
Earth, atmospheric, and ocean sciences	681	209	133	107	143	26	11	42
Mathematics	997	320	205	153	403	119	90	41
Medical and other health sciences	844	388	91	171	522	40	175	146
Physical sciences	1,824	765	297	137	820	256	168	70
Psychology	940	720	41	55	191	15	7	12
Social sciences	4,042	1,153	693	577	987	98	114	211
Non-S&E	5,542	2,844	601	569	2,056	128	248	498

[a] North America includes Bermuda, Canada, Clipperton Island, Greenland, Mexico, and Saint Pierre and Miquelon. South America includes Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Falkland Islands (Islas Malvinas), French Guyana, Guyana, Paraguay, Peru, South Georgia and South Sandwich Islands, Suriname, Uruguay, and Venezuela.

[b] Middle East includes Akrotiri, Armenia, Azerbaijan, Bahrain, Dhekelia, Gaza Strip, Georgia, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, United Arab Emirates, West Bank, and Yemen.

Note(s)

Data include temporary visa holders and non-U.S. citizens with unknown visa status.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2016), 2015 Survey of Earned Doctorates (SED).

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The Middle East

Between 1995 and 2015, Middle Eastern students earned fewer U.S. S&E doctorates (about 9,000) than did students from Asia, Europe, or the Americas (▦ Table 2-15, ▦ Table 2-16, and ▦ Table 2-17). Students from Iran earned the largest number of U.S. S&E doctorates from this region, followed by those from Jordan and Saudi Arabia. A larger proportion of Iranian doctorate recipients (68%) than of Jordanian or Saudi Arabian doctorate recipients (37% and 27%, respectively) earned their degrees in engineering. A larger proportion of doctorate recipients from Saudi Arabia than from Jordan or Iran earned their doctorates in the social sciences or in non-S&E fields.

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[1] The Survey of Graduate Students and Postdoctorates in Science and Engineering (GSS) was redesigned in 2007. Because of methodological changes, the data collected after 2007 are not strictly comparable with those collected before 2007. To maintain some data continuity, the S&E data in this chapter excludes three new fields added in 2007 for all subsequent years. Beginning in 2008, a more rigorous follow-up was conducted with institutions to exclude reporting of practitioner-oriented graduate degree programs. Some or most of the declines in psychology and other health fields after 2008 are likely due to this increased effort rather than changes in actual enrollments. In 2014, the survey frame was updated, which resulted in adding 151 newly eligible institutions, and excluding two private for-profit institutions offering mostly practitioner-based graduate degrees because they were determined to be no longer eligible. This frame update increased the total number of science, engineering, and health graduate students by 2.5%, postdoctorates by 1.9%, and nonfaculty researchers by 1.9% over the previous frame. Because of these survey changes over time, data comparisons across years should be made with caution. For more information, please see Technical Notes, Data Comparability in the *Survey of Graduate Students and Postdoctorates in Science and Engineering, Fall 2015* (https://ncsesdata.nsf.gov/datatables/gradpostdoc/2015/#tabs-2/).

[2] For additional data on graduate enrollment by sex and by race and ethnicity, please see data tables under Graduate enrollment in *Women, Minorities, and Persons with Disabilities in Science and Engineering* (https://nsf.gov/statistics/2017/nsf17310/data.cfm/) and data tables in the GSS (https://nsf.gov/statistics/srvygradpostdoc/#tabs-2/).

[3] See NSF/NCSES 2017a for more detail on enrollment of international students by sex.

[4] The data include active foreign national students on F-1 visas in the SEVIS database, excluding those on OPT (temporary employment directly related to the student's major area of study during or after completing the degree program).

[5] For example, an international student who is about to earn a master's degree and stays in the United States to pursue a doctoral degree would remain in the SEVIS database. It is not possible to determine the extent to which international students stay to pursue another degree because of the way the data are collected.

[6] Data on degree completion from NCES were obtained from WebCASPAR (https://webcaspar.nsf.gov/). Data uploaded in WebCASPAR correspond to NCES provisional data, which undergo all NCES data quality control procedures and are imputed for nonresponding institutions. These data are used by NCES in its First Look (Provisional Data) publications.

[7] Data for racial and ethnic groups are for U.S. citizens and permanent residents only.

[8] Data on degree completion from NCES were obtained from WebCASPAR (https://webcaspar.nsf.gov/). Data uploaded in WebCASPAR correspond to NCES provisional data, which undergo all NCES data quality control procedures and are imputed for nonresponding institutions. These data are used by NCES in its First Look (Provisional Data) publications.

[9] In 2008, NCES allowed optional reporting in three new doctoral degree categories: doctor's—research/scholarship, doctor's—professional practice, and doctor's—other. Degrees formerly classified as professional degrees (e.g., MDs, JDs) could then be reported as doctoral degrees, most often as doctor's—professional practice. Data for 2008 and 2009 included only those doctorates reported under the old category plus those reported as doctor's—research/scholarship. Data for 2010 and 2011 included data reported as doctor's—research/scholarship because the old category was eliminated. As a result of these methodological changes, doctor's—research/scholarship degrees in other health sciences declined sharply between 2009 and 2010.

[10] For the corresponding proportion in the 1990s, see NSB 2008.

International S&E Higher Education

In the 1990s, many countries, coming to view an educated population and workforce as a valuable national resource, began to expand their higher education systems and broaden participation in higher education. At the same time, flows of students worldwide increased, often reflecting government incentives and programs. More recently, several countries have adopted policies to encourage the return of students who studied abroad, to attract international students, or both. As the world becomes more interconnected, students who enroll in tertiary (postsecondary) institutions outside their own countries have opportunities to expand their knowledge of other societies and languages and improve their employability in globalized labor markets.

Higher Education Expenditures

One indicator of the importance of higher education is the percentage of a nation's resources devoted to it as measured by the ratio of expenditures on tertiary education institutions to gross domestic product (GDP). This indicator varies widely among members of the OECD, an intergovernmental group of developed economies. Nearly half of OECD members spend more than the average of 1.5% of a nation's GDP on tertiary education institutions, and only Canada, the United States, South Korea, Chile, and Estonia spend 2% or more.[1] According to the most recently available data from the OECD, in 2013, the United States spent the highest proportion of GDP on tertiary education institutions compared with all other OECD countries, followed by Canada,[2] South Korea, Chile, and Estonia (Appendix Table 2-33). Between 2005 and 2013, U.S. expenditures on tertiary education as a percentage of GDP were about 70% higher than the OECD average and about 90% higher than the European Union (see Glossary for member countries) average. Between 2000 and 2015, expenditures on tertiary education institutions as a percentage of GDP rose in most OECD countries, particularly in Estonia, Russia, Chile, and the Czech Republic (40% growth or higher).

Higher education financing data are not always fully comparable across different nations. They can vary between countries for reasons unrelated to actual expenditures, such as differences in measurement, types and levels of government funding included, types and levels of education included, and the prevalence of public versus private institutions.[3]

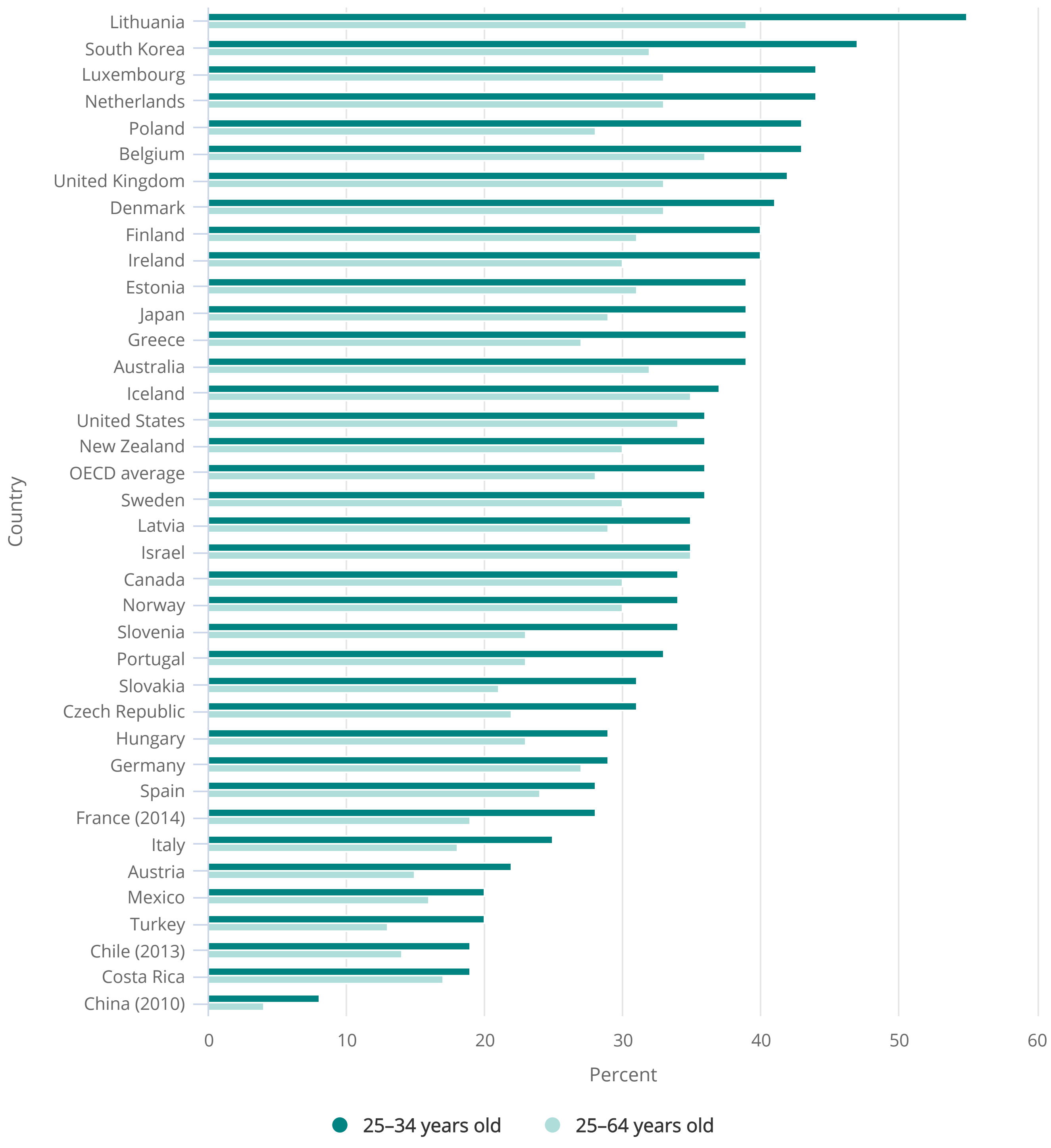
Educational Attainment

Educational attainment, measured as the proportion of a population that has reached a specific level of education, is often used as a proxy for human capital and the skill levels associated with that particular education level (OECD 2016). Higher education in the United States expanded greatly after World War II. As a result, the U.S. population led the world in educational attainment for several decades. Because of this, the United States offered clear advantages for firms whose work would benefit from the availability of a highly educated workforce. In the 1990s, however, many countries in Europe and Asia began to expand their higher education systems. Some of them have now surpassed the United States in the attainment of bachelor's or higher-level degrees among their younger cohorts. The generational shift in attainment so visible in many systems is not visible in the United States. Over time, the expansion of higher education elsewhere has substantially diminished the U.S. educational advantage.

Although the United States continues to be among the top countries with the highest percentage of the population ages 25–64 with a bachelor's degree or higher, many countries have surpassed the United States in the percentage of the younger population (ages 25–34) with a bachelor's degree or higher (Figure 2-23).[4]

FIGURE 2-23

Attainment of bachelor's or higher degrees, by country and age group: 2015



OECD = Organisation for Economic Co-operation and Development.

Note(s)

Data include degrees at International Standard Classification of Education (ISCED) 2011 levels 6 (bachelor's or equivalent), 7 (master's or equivalent), and 8 (doctorate or equivalent). Data are not comparable with data presented in earlier years because of a change to ISCED 2011. Countries for which data at the short-cycle tertiary level (ISCED 5) were not available independently are not included.

Source(s)

OECD, *Education at a Glance 2016: OECD Indicators* (2016).

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First University Degrees in S&E Fields

More than 22 million students worldwide earned first university degrees in 2014 (see sidebar Comparability of International Data in Tertiary Education and Glossary), with more than 7.5 million of these in S&E fields (Appendix Table 2-34).[5]

SIDEBAR

Comparability of International Data in Tertiary Education

Education systems differ widely across the world. To ensure that international statistics and indicators are comparable, most countries collect and report their education data under the United Nations Educational, Scientific and Cultural Organization (UNESCO) International Standard Classification of Education (ISCED), developed in collaboration with different countries and international organizations such as the Organisation for Economic Co-operation and Development (OECD) and Eurostat (OECD, European Union [EU], UNESCO Institute for Statistics [UIS] 2015). Mapping a country's educational programs into the ISCED structure helps ensure that the international comparisons are more transparent and consistent.

The first ISCED classification was developed by UNESCO in the mid-1970s and was first revised in 1997. The most recent revision, the ISCED 2011, incorporated the major changes in the structure of degree levels brought in by the Bologna Process in Europe in terms of degree levels. In the ISCED 1997, tertiary programs had been grouped into levels 5A (programs leading to entry to advanced research programs) and 5B (programs not leading to entry to advanced research programs (see Glossary) and doctoral level 6. The new ISCED 2011 allocates four different levels to tertiary education: levels 5–8. Level 5 includes short-cycle tertiary education, level 6 includes the bachelor's or equivalent level, level 7 includes the master's or equivalent level, and level 8 includes the doctoral or equivalent level.

In addition, a separate but related process redesigned the fields of study classifications in the ISCED Fields of Education and Training (ISCED-F); these new standards were adopted in 2013 (UNESCO Institute for Statistics 2014).

Science and Engineering Indicators 2018 is the first edition to present statistics collected under the ISCED 2011 and the ISCED-F; previous editions had presented data collected under the ISCED 1997. As a result of these changes, there are several differences between the higher education international data reported in this volume and in past volumes.

At the undergraduate level, the international comparisons in this volume present first degree data corresponding to ISCED 2011 level 6 (first degrees) and level 7 (long first degrees). Some countries (e.g., Germany, Belgium, Switzerland) reclassified some vocationally oriented programs previously classified as ISCED level 5B. As a result, the total numbers of first university degrees for these countries are different under the new classification compared with the previous classification. At the doctoral level, the data corresponding to the ISCED 2011 level 8 are similar to the doctoral degrees reported in the past.

The changes in ISCED-F affect the following fields:

- The data for engineering in this volume correspond to the ISCED-F 2013 "engineering, manufacturing, and construction," which includes engineering and engineering trades, manufacturing and processing, and architecture and construction. In addition, "environmental protection" was a newly added discipline to this broad field of engineering.
- The data for agriculture include "veterinary."
- The data for social and behavioral sciences include "journalism and information."

Because of these changes, the international higher education data have a higher degree of international comparability than in the past. This is because (1) the data for the majority of the countries were collected under the same OECD, EU, and UIS guidelines; and (2) the field groupings in the ISCED-F now have more in common with the aggregation of fields used in China, a major degree producer. For example, China statistics include “architecture” and “landscape architecture” under “engineering” and “veterinary” under “agricultural sciences” (China Ministry of Education 2011).

For comparability purposes, U.S. data in the international tables correspond to the ISCED-F classification of fields and, as a result, the numbers reported in each of the broad fields are different from those reported in tables and graphics that examine domestic trends in higher education.

These worldwide totals include only countries for which relatively recent data are available (primarily countries in Asia, Europe, and the Americas) and are therefore underestimates of the global total. Asian universities accounted for more than 4 million of the world’s S&E first university degrees in 2014, with more than half of them in engineering. Students across Europe (including Eastern Europe and Russia) earned more than 1.5 million S&E first university degrees (about 40% of them in engineering), and students in North America earned nearly 1 million S&E first university degrees in 2014 (24% in engineering). In terms of individual countries, India and China awarded the largest numbers of first university degrees in S&E (1.9 and 1.7 million, respectively), followed by the United States (742,000), Russia (429,000), and Japan (316,000).

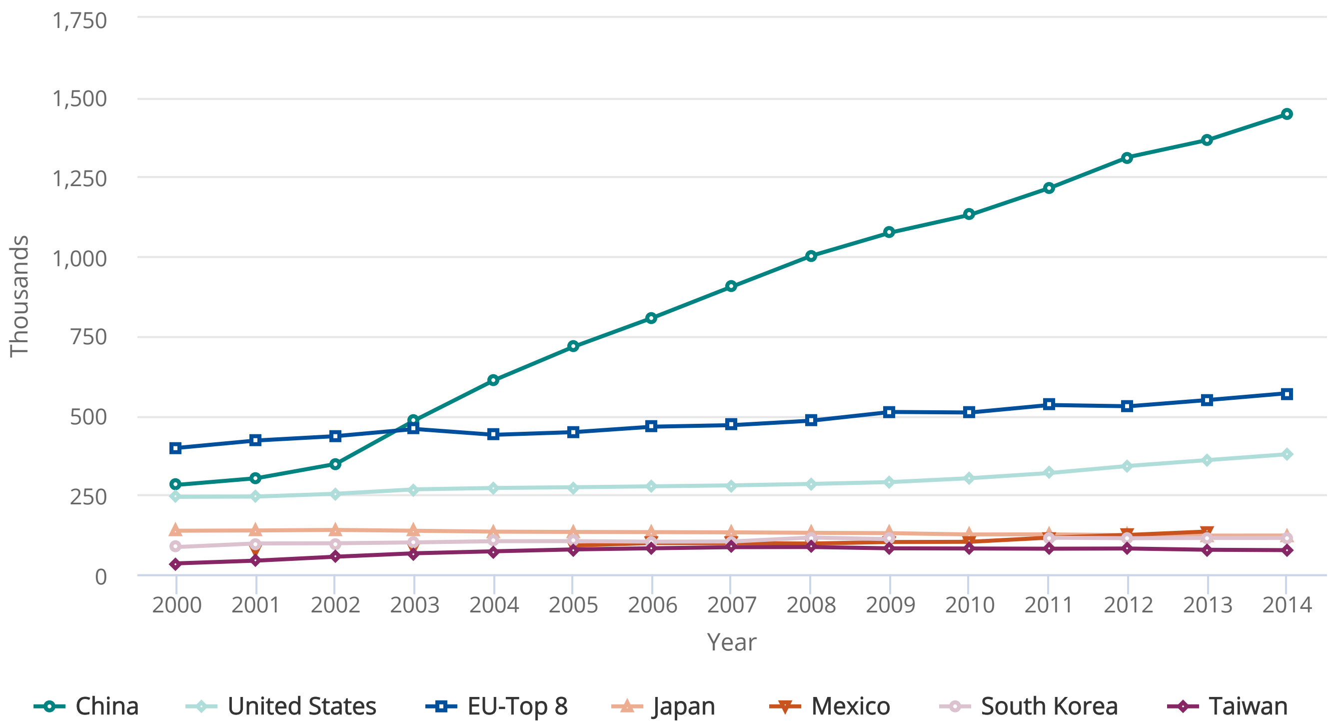
In several countries around the world, the proportion of first university degrees in S&E fields was higher than in the United States. Nearly half or more of all first university degrees in Japan, Iran, China, and Israel were in S&E fields, compared with nearly 40% in the United States. In 2014, about 14% of all bachelor’s degrees awarded in the United States and worldwide were in the natural sciences (physical, biological, computer, and agricultural sciences, as well as mathematics and statistics). This proportion was similar to the proportions of first university degrees awarded in the natural sciences in Canada, New Zealand, the Czech Republic, South Africa, Germany, and Armenia, but it was lower than the proportion awarded in the United Kingdom (21%).

Between 2000 and 2014, the number of S&E first university degrees awarded in China, Taiwan, Germany,[6] Turkey, and Romania at least doubled; it also grew, albeit at a slower rate, in Australia,[7] Mexico, the United Kingdom, and the United States; in France and Japan, it declined (by 5% and 11%, respectively) (Appendix Table 2-35).

In China, first university degrees increased greatly in all fields, with a larger increase in non-S&E than in S&E fields. Growth in natural sciences and engineering degrees in China accounted for most of the country’s increase in S&E first university degrees: an increase of almost 1.2 million degrees and up more than 400% from 2000 to 2014 (Figure 2-24; Appendix Table 2-35). China has traditionally awarded a large proportion of its first university degrees in engineering, but the percentage declined from 43% in 2000 to 33% in 2014 (Appendix Table 2-35).

FIGURE 2-24

First university natural sciences and engineering degrees, by selected country or economy: 2000–14



EU = European Union.

Note(s)

Natural sciences include agricultural sciences; biological sciences; computer sciences; earth, atmospheric, and ocean sciences; and mathematics. Data are not comparable with data presented in earlier years because of a change to International Standard Classification of Education 2011 and to a more aggregated taxonomy of fields. To facilitate international comparison, data for the United States reflect the most recent classification in the International Standard Classification of Education Fields of Education and Training (ISCED-F), which varies slightly from the National Science Foundation classification of fields presented in other sections of the chapter. Data are not available for all countries or economies for all years. The EU-Top 8 total includes aggregated data for the eight EU countries producing the highest number of S&E first university degrees in 2014: UK, Germany, France, Poland, Italy, Spain, Romania, and the Netherlands.

Source(s)

National Bureau of Statistics of China, *China Statistical Yearbook*, annual series (Beijing) (various years); Government of Japan, Ministry of Education, Culture, Sports, Science and Technology, Survey of Education (2014); Ministry of Education, Educational Statistics of the Republic of China (Taiwan): 2015 (2016); United Nations Educational, Scientific and Cultural Organization (UNESCO) Institute for Statistics database, special tabulations (2016); Organisation for Economic Co-operation and Development (OECD), OECD.Stat, https://stats.oecd.org/; National Center for Education Statistics, Integrated Postsecondary Education Data System (IPEDS), Completions Survey; National Science Foundation, National Center for Science and Engineering Statistics, WebCASPAR database, https://ncsesdata.nsf.gov/webcaspar/.

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In 1999, 29 European countries, through the Bologna Declaration, initiated a system of reforms in higher education throughout Europe. The goal of the Bologna Process was to harmonize certain aspects of higher education within participating countries so that degrees were comparable; credits were transferable; and students, teachers, and researchers could move freely from institution to institution across national borders. Ten years later, 48 countries launched the European Higher Education Area to implement these higher education reforms in Europe. In recent years, countries have made considerable changes: they have modified higher education structures by implementing three degree cycles (bachelor's, master's, and doctorate), developed quality assurance systems, and established mechanisms to facilitate mobility (Education, Audiovisual and Culture Executive Agency [EACEA] 2012). A recent report that examined data in the areas of access, retention, and employability across 36 education systems, however, indicated that most European countries have been slow to set clear goals or monitor progress in those areas (EACEA 2014).

S&E First University Degrees by Sex

Women earned half or more of first university degrees in S&E in many countries around the world in 2014, including the United States, Canada, and several smaller countries. Most large countries in Europe are not far behind, with women earning more than 40% of S&E first university degrees. In most countries in the Middle East, except for Iran, women earned nearly half or more of the S&E first university degrees. In Asia, women generally earn about one-third or fewer of the first university degrees awarded in S&E fields. For example, in Taiwan, women earn 26% of the S&E first university degrees; in Japan, 29%; in South Korea, 34%; in Singapore, 36%. Malaysia is the exception, with 55% of its S&E first university degrees awarded to women in 2015 (Appendix Table 2-36).

In the United States and Canada, more than half of the S&E first university degrees earned by women were in the social and behavioral sciences, and less than 10% were in engineering. In contrast, in South Korea and Singapore, nearly half of the S&E first university degrees earned by women were in engineering. Among the largest producers of S&E degrees (those in which 40% of their first university degrees were in S&E), other countries with relatively high proportions of women earning first university degrees in engineering include Portugal (37%), Iran (35%), Romania (35%), and Malaysia (33%).

International Comparison of S&E Doctoral Degrees

More than 230,000 S&E doctoral degrees were awarded worldwide in 2014.[8] The United States awarded the largest number of S&E doctoral degrees of any country (about 40,000), followed by China (about 34,000), Russia (about 19,000), Germany (about 15,000), the United Kingdom (about 14,000), and India (about 13,000) (Appendix Table 2-37). About 73,000 S&E doctoral degrees were earned in the EU (including the United Kingdom and Germany).

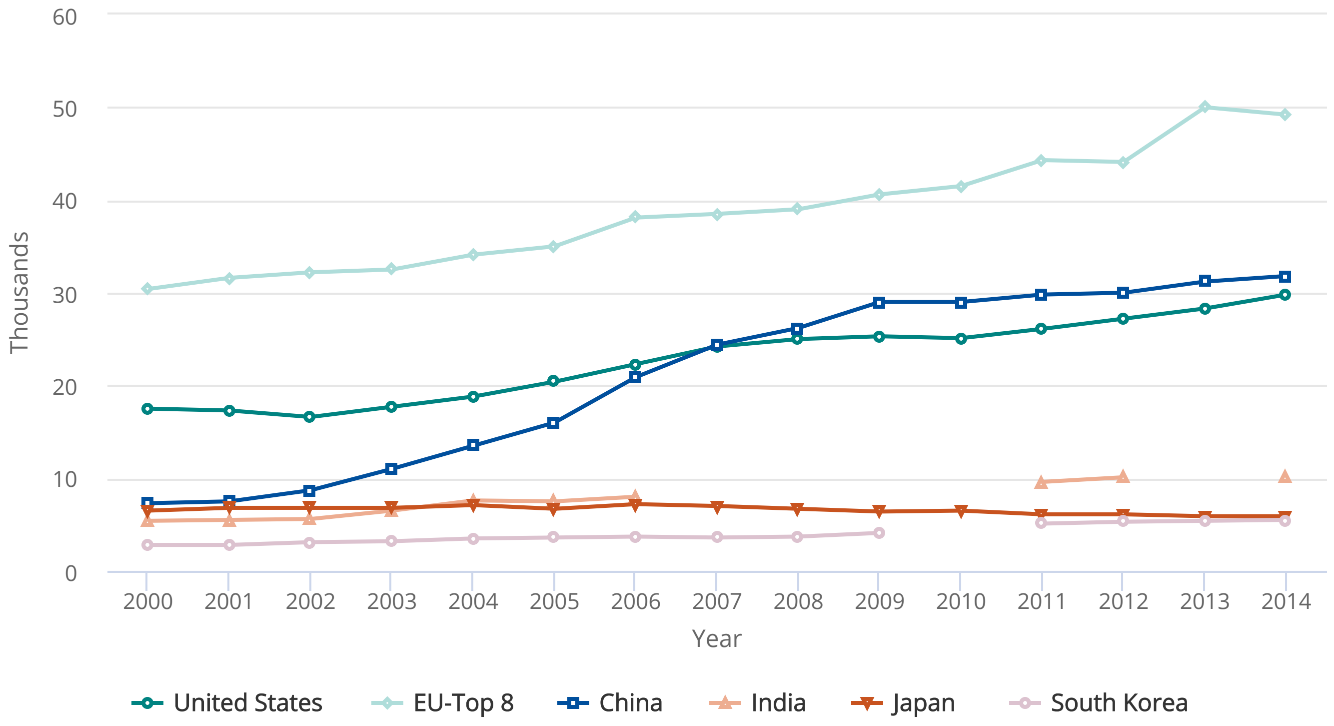
The number of S&E doctoral degrees awarded in China rose steeply between 2000 and 2009, but the increase has slowed since then. Although the rise was steeper in China, doctoral production also increased in the United States (Appendix Table

2-38 and Appendix Table 2-39). In the United States, about 37% of these doctorates were awarded to temporary visa holders.[9] Many of these doctorate recipients stay in the United States after obtaining their degree (for a discussion on "stay rates" of doctorate recipients who are temporary visa holders, see Chapter 3)

In 2007, China surpassed the United States as the world's largest producer of natural sciences and engineering doctoral degrees, but the numbers of doctoral degrees in these fields in these two countries remain close (Figure 2-25). The high growth of graduate education in China has been the result of large government investments in higher education over the last 20 years, intended to establish world-class universities in this country. Project 211 and Project 985 are examples of programs launched by the Chinese government in the mid-1990s to establish and strengthen institutions of higher education and key fields of study as a national priority (Lixu 2004).[10]

FIGURE 2-25

Natural sciences and engineering doctoral degrees, by selected country: 2000–14



EU = European Union.

Note(s)

Natural sciences and engineering include biological, physical, earth, atmospheric, ocean, and agricultural sciences; computer sciences; mathematics; and engineering. To facilitate international comparison, data for the United States reflect the most recent classification in the International Standard Classification of Education Fields of Education and Training (ISCED-F), which varies slightly from the National Science Foundation classification of fields presented in other sections of the chapter. Data are not available for all countries for all years. The Top 8 EU total includes aggregated data for the eight EU countries with the highest number of S&E doctoral degree awards in 2014: UK, Germany, France, Spain, Italy, Portugal, Sweden, and Romania.

Source(s)

China—National Bureau of Statistics of China, *China Statistical Yearbook*, annual series (Beijing) (various years); India—Government of India, Ministry of Human Resource Development, Department of Higher Education, All India Survey on Higher Education (2014); Japan—Government of Japan, Ministry of Education, Culture, Sports, Science and Technology, Survey of Education (2014); United Nations Educational, Scientific and Cultural Organization (UNESCO), Institute for Statistics database, special tabulations (2016); United States—National Center for Education Statistics, Integrated Postsecondary Education Data System (IPEDS), Completions Survey; National Science Foundation, National Center for Science and Engineering Statistics, WebCASPAR database, https://ncsesdata.nsf.gov/webcaspar/.

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In the United States, as well as in the United Kingdom, France, Germany, Italy, Spain, Switzerland, Poland, Ireland, and Estonia, the largest numbers of S&E doctoral degrees were awarded in the natural sciences, including the physical and biological sciences, and mathematics and statistics (Appendix Table 2-38). In many other countries, the proportion of S&E doctoral degrees in engineering is 40% or greater; that is the case, for example, in Sweden, Slovakia, Latvia, Greece, Finland, Bulgaria, Belgium, and Austria.

In Asia, China has been the largest producer of S&E doctoral degrees since 2000 (Appendix Table 2-39). As China's capacity for advanced S&E education increased, the number of S&E doctorates awarded rose from about 8,000 in 2000 to more than 34,000 in 2014. Despite the growth in the quantity of doctorate recipients, some question the quality of the doctoral programs in China (Cyranoski et al. 2011). The rate of growth in doctoral degrees in S&E and in all fields has considerably slowed starting in 2010 (Appendix Table 2-39), after an announcement by the Chinese Ministry of Education indicating that China would begin to limit admissions to doctoral programs and focus more on the quality of graduate education (Mooney 2007).

Between 2000 and 2014, the number of S&E doctorates awarded in India, South Korea, and Taiwan more than doubled; in Japan, the numbers rose consistently through 2006 but declined since then). In China, Japan, South Korea, and Taiwan, more than half of S&E doctorates were awarded in engineering. In India, 58% of the S&E doctorates were awarded in the natural sciences, computer sciences and agricultural sciences, 22% in the social and behavioral sciences, and 20% in engineering (Appendix Table 2-39).

Women earned 42% of S&E doctoral degrees awarded in the United States in 2014, about the same percentage earned by women in Canada and the EU (Appendix Table 2-40).[11] Women earned more than half of S&E doctoral degrees in Bulgaria, Croatia, Latvia, Lithuania, Poland, Slovenia, and Argentina but less than 25% of those in South Korea and Taiwan.

International Student Mobility

Governments around the world have increasingly come to regard movement toward a knowledge-based economy as key to economic progress. Realizing that this requires a well-trained workforce, they have invested in upgrading and expanding their higher education systems and broadening participation in them. In most instances, government spending underwrites these initiatives.

Recent investments by several governments to send large numbers of their students to study abroad are a strategy for workforce and economic development. Examples include the Brazil Scientific Mobility Program (also known as Science without Borders), launched officially in July 2011, which provides scholarships to Brazilian students to study in STEM fields in universities in the United States.[12] In 2013, the Mexican government announced its Proyecta 100,000 program, which plans to send 100,000 students to study in the United States and to welcome 50,000 U.S. citizens to study in Mexico by 2018 (Helms and Griffin 2017; Lloyd 2014). The Chinese government has established the China Scholarship Council, a nonprofit affiliated with the Ministry of Education with the goal to provide financial assistance to Chinese citizens to study abroad, as well as to foreign citizens to study in China (China Scholarship Council 2017). Similarly, the government of Saudi Arabia has invested considerably in a scholarship program launched in 2005 that has supported study abroad programs for more than 100,000 Saudi students throughout the world, at an estimated cost of at least $5 billion since the program's inception. In 2016, however, a tighter national budget in Saudi Arabia has resulted in a 12% reduction in financial support for this initiative (Knickmeyer 2012; Walcutt 2016). The EU set the goal that 20% of its higher education graduates should have experienced tertiary-level study or training abroad by 2020 (OECD 2016).

Students have become more internationally mobile in the past two decades, and countries are increasingly competing for them. According to data from UNESCO/UIS, the number of internationally mobile students who pursued a higher education degree more than doubled between 2000 and 2014, to 4.3 million.[13] In general, students migrate from developing countries to the more developed countries and from Europe and Asia to the United States. However, a few countries have emerged as regional hubs for certain geographic regions—for example, Australia, China, and South Korea for East Asia and South Africa for sub-Saharan Africa (Bhandari, Belyavina, and Gutierrez 2011; UNESCO 2009). In Asia, two new programs, ASEAN International Mobility for Students and Passage to ASEAN, encourage student mobility within Asia, although the level of student mobility within the region is still low, except for the student exchanges between Malaysia and Indonesia. In addition, several countries have set targets for increasing the numbers of international students they host; among these are Jordan (which plans to host 100,000 students by 2020), Singapore (150,000 by 2015), Japan (300,000 by 2025), and China (500,000 by 2020) (Bhandari and Belyavina 2012).

Decisions about whether and where to study abroad are complex (OECD 2016). Some students migrate temporarily for education, whereas others remain abroad permanently after completing their studies. Some factors influencing the decision to seek a degree abroad include the policies of the countries of origin regarding sponsoring their citizens' studies abroad, the tuition fee policies of the countries of destination, the financial support the countries of destination offer to international students, the cost of living and exchange rates that affect the cost of international education, and the quality of the programs and the perceived value of obtaining a foreign credential. The long-term return on investment from international education also depends on how international degrees are recognized by the labor market in the country of origin or elsewhere. For host countries, enrolling international students can help raise revenues from higher education and can be part of a larger strategy to attract highly skilled workers, particularly as demographic changes in many developed countries cause their own populations of college-age students to decrease (OECD 2012) (Appendix Table 2-41).

In recent years, many countries have expanded their provision of transnational education. One growing trend is the establishment of branch campuses: offshore programs established by higher education institutions in foreign countries. For local students, branch campuses provide the opportunity to earn degrees from foreign universities without leaving their home countries. For the institution venturing into a new country, meeting enrollment and financial goals without diluting quality standards is often a challenge. Branch campuses that bring in faculty from other countries can also fulfill some of the demand for highly qualified instructors that local higher education institutions cannot meet (UNESCO/UIS 2014).

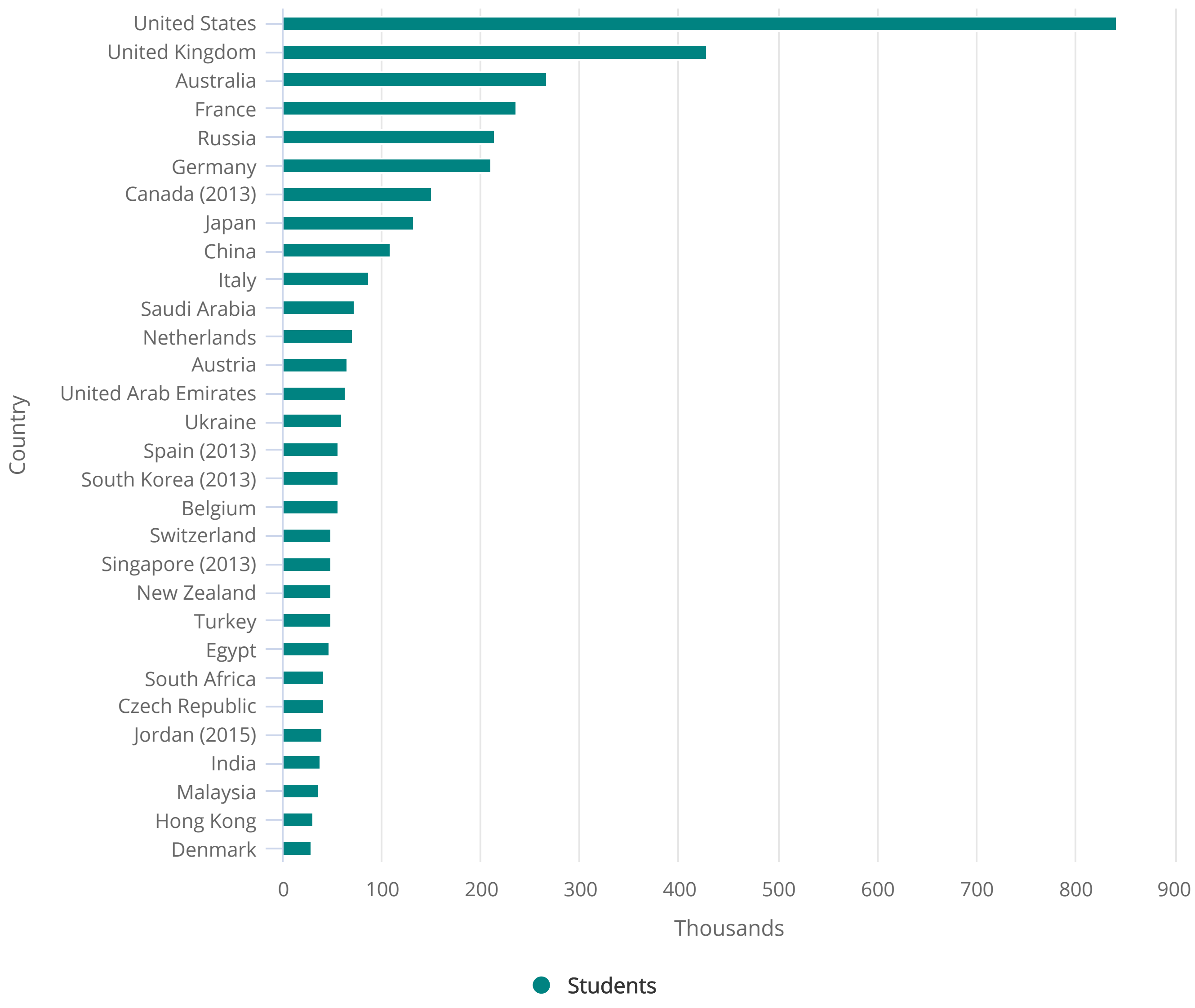
According to the State University of New York at Albany's Cross-Border Education Research Team (C-BERT 2017), a clearinghouse of information and research on transnational education, as of January 2017, there were 310 international branch campuses in operation. C-BERT defines a branch campus as "an entity that is owned, at least in part, by a foreign higher education provider; operated in the name of the foreign education provider; and provides an entire academic program, substantially on site, leading to a degree awarded by the foreign education provider." Exporting countries (i.e., home countries of the institutions establishing branch campuses) totaled 34, and importing countries (i.e., host countries for branch campuses) totaled 84. The largest exporters of branch campuses, in order of the number of branch campuses established, were the United States (109 branch campuses), the United Kingdom (45), France (31), Russia (22), and Australia (21). The largest importers of branch campuses, in order of the number of branch campuses they hosted, were China (38 branch campuses), the United Arab Emirates (33), United Arab Emirates at Dubai (32), Malaysia (16), Singapore (15), and Qatar (12). In some cases, branch campuses are a part of what countries designate as an international "education hub." C-BERT defines an education hub as "a designated region intended to attract foreign investment, retain local students, build a regional reputation by providing access to high-quality education and training for both international and domestic students, and create a knowledge-based economy." An education hub can include different combinations of domestic and international institutions, branch campuses, and foreign partnerships within the designated region. Examples of education hubs include Qatar, the United Arab Emirates, Abu Dhabi, Dubai, Hong Kong, Malaysia, Singapore, and Botswana (C-BERT 2017; Knight 2014).

More internationally mobile students (undergraduate and graduate) go to the United States than to any other country (19% of internationally mobile students worldwide) (📊Figure 2-26). Other top destinations for international students include the

United Kingdom (10%), Australia (6%), France (5%), Russia (5%), and Germany (5%). Together with the United States, these countries receive about half of all internationally mobile students worldwide. Although the United States remains the destination for the largest number of internationally mobile students worldwide, its overall share has declined from 25% in 2000 to 19% in 2014 (OECD 2016). As in other countries, the proportion of internationally mobile students in the United States is higher at the graduate than at the undergraduate level (see Appendix Table 2-18, Appendix Table 2-21, Appendix Table 2-27, and Appendix Table 2-29).

FIGURE 2-26

Internationally mobile students enrolled in tertiary education, by selected country: 2014



Note(s)

Data are based on the number of students who have crossed a national border and moved to another country with the objective of studying (i.e., mobile students).

Source(s)

United Nations Educational, Scientific and Cultural Organization (UNESCO), Institute for Statistics database, special tabulations (2016).

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International Student Enrollment in Selected Countries

United Kingdom

Since the late 1990s, the United Kingdom has been actively working to improve its position in international education, by recruiting international students to study in the country and by expanding its provision of transnational education (British Council 2015; United Kingdom Council for International Student Affairs [UKCISA] 2017). Between 2006 and 2016, international student enrollment in S&E fields in the United Kingdom increased by about 36,000 international students at the undergraduate level and by about 18,000 at the graduate level (Appendix Table 2-42). As in other countries, the proportion of international students in S&E is much higher at the graduate than at the undergraduate level. For example, in 2015–16, international students were 14% of all undergraduates in the United Kingdom (an increase from 10% in 2005–06), compared with 47% at the graduate level (an increase from 43% in 2005–06). Within S&E, international students were particularly prevalent in engineering. At the undergraduate level, international students were close to one-quarter of all engineering students in 2016; at the graduate level, they accounted for the majority of the students in engineering and in mathematics and computer sciences. China has been the main country sending S&E students to the United Kingdom during this period. However, the number of S&E students from Hong Kong, Romania, and the United States grew considerably at the undergraduate level. In 2016, the United States was among the top 5 countries sending undergraduates studying S&E to the United Kingdom; it was not among the top 10 countries a decade earlier. At the graduate level, in this 10-year period, the number of S&E students from Nigeria nearly doubled, and Italy and Saudi Arabia became 2 of the top 10 countries sending S&E students to the United Kingdom (Appendix Table 2-42).

Japan

In the context of slowing student enrollment, in 2008, the Japanese government announced plans to triple international enrollment within 12 years (McNeil 2008, 2010). Although Japan succeeded in increasing its enrollment of international students between 2004 and 2016 (in S&E and in all fields), growth has slowed considerably in the last 4 years (Appendix Table 2-43; Appendix Table NSB 2012 2-42; Appendix Table NSB 2014 2-46), perhaps caused in part by the March 2011 earthquake and tsunami (McNeil 2012). In 2016, nearly 70,000 international students were enrolled in S&E programs in Japanese universities, similar to the preceding 4 years and up from 57,000 in 2004. As in other countries, international students accounted for a smaller proportion of students at the undergraduate than at the graduate level in 2014 (3% of undergraduate and 19% of graduate S&E students). The vast majority of the international students were from Asia. In 2016, Chinese students accounted for slightly more than half of the international S&E undergraduate students and graduate students in Japan. South Koreans were 16% of the international undergraduates and 6% of the international graduate students. Vietnam, Malaysia, Indonesia, Thailand, and Taiwan are among the top 10 locations of origin that send both undergraduate and graduate students to Japan (Appendix Table 2-43).

Canada

International students also constitute a larger share of enrollment at the graduate than at the undergraduate level in Canada (Appendix Table 2-44). Between 2004 and 2014, the proportion of international enrollment in Canadian universities grew slightly, from 6% to 7% at the undergraduate level and from 20% to 21% at the graduate level. In 2014, the highest percentages of international S&E students were in mathematics and computer sciences and in engineering, at both degree levels. At the undergraduate level, China was the top country of origin of international S&E students in Canada, accounting for 29% of international undergraduate students, followed by France and the United States (14% and 10%, respectively). The proportion of international undergraduate S&E students in Canada from China and France increased considerably between 2004 and 2014, while the proportion of students from the United States declined. At the graduate level, the top country of origin of international S&E students was also China with close to 3,700 students, but the country of origin of graduate S&E students was diverse. For example, France and India each sent about 2,500 S&E students to Canada, and Iran sent about

1,900. Unlike undergraduate students, during 2004 and 2014, the proportion of international graduate students from China declined slightly, and the proportion of those from France and the United States increased. The proportion of Indian S&E graduate students studying in Canada increased from 5% to 13% between 2004 and 2014, and the proportion of Iranian S&E students doubled to 10% in 2014.

U.S. Students Studying Abroad

Although the United States hosts the largest number of international students worldwide, U.S. students constitute a relatively small share of international students worldwide. About 70,000 U.S. students (in all fields) were reported as international students by OECD and OECD partner countries in 2012, far fewer than the number of international students from China, India, South Korea, Germany, Turkey, or France. The main destinations of U.S. students were the United Kingdom (about 16,600), Canada (about 9,600), Germany (about 4,300), France (about 3,900), New Zealand (about 3,200), and Australia (about 2,900)—mostly English-speaking OECD countries (OECD 2014). Given the relatively low number of U.S. students who study abroad and the importance of international experience in a globalized world, in 2014, the Institute of International Education (IIE) established Generation Study Abroad. This 5-year initiative has the goal to increase the number of U.S. students studying abroad, in credit and degree programs, to about 600,000 by 2019 (IIE 2017b).

About 300,000 U.S. university students enrolled in study abroad programs in the 2014–15 academic year (credit mobility—see Glossary), a 3% increase from the preceding year but almost double the number from 2000–01 (IIE 2016). Nearly 40% were enrolled in programs during the summer term, about one-third enrolled in programs lasting one semester, and nearly a quarter enrolled in short-term programs lasting up to 8 weeks. Only 3% enrolled for the full academic year, and very few enrolled for one or two quarters. The vast majority were undergraduates, primarily juniors and seniors; about 10% were master's students; and 1% were doctoral students. Two-thirds of the U.S. students studying abroad were women, and nearly three-quarters were white. More than one-third were studying in S&E fields: 17% in social sciences, 8% in physical or life sciences, 5% in engineering, 2% in mathematics or computer sciences, and 2% in agricultural sciences; these proportions have been fairly stable since 2000–01. The leading destinations for study abroad programs in the 2014–15 academic year were the United Kingdom, Italy, and Spain, followed by France and China.[14]

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[1] For most countries, the data in Appendix Table 2-33 include public and private sources.

[2] The most recent data available from Canada correspond to 2012.

[3] According to an international database compiled by the State University of New York at Albany's Program for Research on Private Higher Education (2011), the United States and Japan have long-standing private higher education sectors, and Western Europe has an almost completely public higher education sector. Eastern and Central Europe and several African countries have recently seen growth in private higher education. In most countries in Latin America, more than half of all higher education institutions are private. In Asia, many governments have encouraged the expansion of private higher education as one of the strategies to deal with high enrollment growth (see sidebar Trends in Higher Education in Asia in NSB 2016). In 2011, about 80% of the students in South Korea and Japan and 60%–64% of the students in Singapore, the Philippines, Nepal, Indonesia, and Cambodia were enrolled in private institutions (UNESCO/UIS 2014).

[4] These data are based on ISCED 2011 and are thus not comparable with data presented in earlier volumes based on ISCED 1997. These data are based on national labor force surveys and are subject to sampling error; therefore, small differences between countries may not be meaningful (OECD 2016).

[5] Data in the international tables are not strictly comparable with those in previous editions of *Science and Engineering Indicators* because of a change in the aggregation of fields of study in data collected by UNESCO/UIS, OECD, and Eurostat. Data for the United States and other countries have been aggregated to match as much as possible.

[6] Comparison with Germany covers 2005–14 because of ISCED 2011 changes.

[7] Comparison for Australia covers 2000–11.

[8] In international degree comparisons, S&E does not include medical or other health fields. This is because international sources cannot separate the MD degrees from degrees in the health fields, and the MDs are professional or practitioner degrees, not research degrees.

[9] For international comparability, the estimated proportion of temporary residents here is based on the U.S. doctoral degree totals in Appendix Table 2-38, which are based on the ISCED 2011 taxonomy of fields (denominator). The numerator comes from the number of temporary residents in Appendix Table 2-32 but excludes the medical fields which are not included in international comparisons because some countries include medical degrees, which are professional rather than research degrees, under this category.

[10] For a discussion on trends in higher education in Asia, see *Indicators 2016* Chapter 2 [2016] section International S&E Higher Education [2016] at https://nsf.gov/statistics/2016/nsb20161/#/report/chapter-2/international-s-e-higher-education.

[11] In the United States, women earned nearly half of the S&E doctoral degrees awarded to U.S. citizens and permanent residents in 2012 (Appendix Table 2-31).

[12] This initiative is part of a broader effort from the Brazilian government to grant 100,000 scholarships to the best students to study abroad at the top universities around the world (IIE 2017a).

[13] Internationally mobile students are those who have crossed a national or territorial border for the purposes of education and are now enrolled outside their country of origin. This concept is different from “foreign students,” who are those who are not citizens of the country where they are enrolled but may, in some cases, be long-term residents or have been born in the country (OECD 2012).

[14] For the most recent data available on degree mobility, please see NSB 2016 for a discussion of this subject in Belyavina, Li, and Bhandari 2013.

Conclusion

S&E higher education in the United States is attracting growing numbers of students. The number of associate's, bachelor's, master's, and doctoral degrees awarded in all fields and in S&E fields continues to rise, having reached new peaks in 2015. At the associate's level, the number of S&E associate's degrees more than doubled; growth was also high in associate's degrees in health technologies. At the bachelor's level, most of the growth in S&E education occurred in the social sciences and in the biological sciences, followed by engineering. In engineering, bachelor's degrees have increased consistently for the last 10 years and have surpassed the record high numbers attained in the mid-1980s; graduate enrollment in engineering has also reached record numbers. Computer sciences degree awards have increased continuously since 2009, after a steep decline in the mid- to late 2000s. The number of master's and doctoral degrees awarded grew in all major S&E fields. In the last decade, growth in doctoral degrees awarded occurred mostly in the natural sciences and engineering fields.

Community colleges play a key role in increasing access to higher education for all citizens. Many U.S. citizen and permanent resident degree holders report earning college credit from a community college. Nearly half of Hispanic undergraduates are enrolled in them. The expected demographic growth in the number of Hispanic students between 20 and 24 years of age will affect community colleges and HHEs.

Over the last two decades, higher education spending and revenue patterns and trends have undergone substantial changes, which intensified during the recent economic downturn. Public institutions faced competing demands in a tight budget environment, caught between declining state appropriations and the need to maintain educational quality and access. Despite the decline in enrollment in 2013–14, net tuition per FTE student continued to increase with the decrease in revenues from state and local appropriations in public institutions, so challenges remain.

Globalization of higher education continues. Universities in several other countries have expanded their enrollment of international S&E students. In the United States, international student enrollment in S&E has recovered since the post-9/11 decline, increasing considerably at the undergraduate and graduate levels in S&E and non-S&E fields, but in the last year international enrollment declined. Overall, the United States continues to attract the largest number of internationally mobile students worldwide, although its share of international students in all fields has dropped since the turn of the century. The U.S. proportion may decrease further if the declining trend in international enrollment continues.

Higher education is facing rapid technological transformations. The growth of distance and online education through MOOCs and similar innovations expands access to knowledge and has the potential to decrease the cost of some degrees, at the same time as pressures have been increasing to reduce rising costs. In computer sciences in particular, students can now obtain certificates that provide them with a specific set of skills they can apply to the job; these provide an affordable and flexible alternative to students' training. However, it is too early to assess whether different types of institutions will widely adopt MOOCs, whether increased access will be accompanied by increased learning, and what consequences distance and online innovations will bring to the higher education landscape.

Glossary

Definitions

Credit mobility: Temporary tertiary education within the framework of enrollment in a tertiary education program at a home institution (usually) for the purpose of gaining academic credit (i.e., credit that will be recognized in that home institution). It is mostly used for study, but it can also take other forms, such as traineeships.

Degree mobility: The physical crossing of a national border to enroll in a degree program at the tertiary level in the country of destination. The degree program would require the students' presence for the majority of courses taught.

European Union (EU): The EU comprises 28 member nations: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, and the United Kingdom. Unless otherwise noted, Organisation for Economic Co-operation and Development data on the EU include all 28 nations.

First university degree: A terminal undergraduate degree program; these degrees are classified as "level 6" or "level 7" in the 2011 International Standard Classification of Education, which was developed by UNESCO. Individual countries use different names for the first university degree (e.g., *corso di Laurea* in Italy, *diplom* in Germany, *licence* in France, and *bachelor's degree* in the United States and in Asian countries).

Internationally mobile students: Students who have crossed a national or territorial border for purposes of education and are now enrolled outside their countries of origin. This term refers to degree mobility in data collected by UNESCO/UIS, OECD, and Eurostat and excludes students who travel for credit mobility.

Massive Open Online Course (MOOC): An online course made available over the Internet without charge to an unlimited number of people.

Natural sciences: Include agricultural; biological; computer; earth, atmospheric, and ocean; and physical sciences and mathematics.

Net tuition revenue: Total revenue from tuition and fees (including grant and loan aid students use to pay tuition); excludes institutional student aid that is applied to tuition and fees.

Science and engineering fields: Degree award data from the Department of Education cover degrees in the following science and engineering fields: astronomy, chemistry, physics, atmospheric sciences, earth sciences, ocean sciences, mathematics and statistics, computer sciences, agricultural sciences, biological sciences, psychology, social sciences, and engineering. At the doctoral level, the medical and health sciences are included under science and engineering because these data correspond to the doctor's-research/scholarship degree level which are research-focused degrees.

Underrepresented minorities: Blacks, Hispanics, and American Indians and Alaska Natives are considered to be underrepresented minorities in S&E.

Key to Acronyms and Abbreviations

ARRA: American Recovery and Reinvestment Act

BPS: Beginning Postsecondary Students

C-BERT: Cross-Border Education Research Team

DOD: Department of Defense

EACEA: Education, Audiovisual and Culture Executive Agency

EU: European Union

FTE: full-time equivalent

GAO: U.S. Government Accountability Office

GDP: gross domestic product

GSS: Survey of Graduate Students and Postdoctorates in Science and Engineering

HBCU: historically black college or university

HHE: high Hispanic enrollment

HSI: Hispanic-serving institution

IIE: Institute of International Education

IPEDS: Integrated Postsecondary Education Data System

ISCED: International Standard Classification of Education

ISCED-F: ISCED Fields of Education and Training

MIT: Massachusetts Institute of Technology

MOOC: massive open online course

MSI: minority-serving institution

NCES: National Center for Education Statistics

NCSES: National Center for Science and Engineering Statistics

NIH: National Institutes of Health

NPSAS: National Postsecondary Student Aid Study

NSB: National Science Board

NSCG: National Survey of College Graduates

NSF: National Science Foundation

OECD: Organisation for Economic Co-operation and Development

OPT: optional practical training

PSM: Professional Science Master's

R&D: research and development

RA: research assistantship

S&E: science and engineering

SEVIS: Student and Exchange Visitor Information System

STEM: science, technology, engineering, and mathematics

TA: teaching assistantship

TCU: tribal college or university

UIS: UNESCO Institute for Statistics

UNESCO: United Nations Educational, Scientific and Cultural Organization

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CHAPTER 3

Science and Engineering Labor Force

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Highlights

U.S. S&E Workforce: Definition, Size, and Growth

The S&E workforce can be defined in several ways: as workers in S&E occupations (6.7 million), as holders of S&E degrees (23.2 million), or as those who use S&E technical expertise on the job (19.4 million). The estimated size of the S&E workforce varies depending on the definitional criteria chosen.

- In 2015, estimates of the size of the S&E workforce ranged from over 6 million to more than 23 million depending on the definition used.
- In 2015, an estimated 6.4 million college graduates were employed in S&E occupations in the United States. The largest S&E occupations were computer and mathematical sciences (3.1 million), followed by engineering (1.7 million). Occupations in life sciences (631,000), social sciences (570,000), and physical sciences (331,000) combined to about the size of the engineering component.

In 2015, about 23.2 million individuals in the United States had a bachelor's or higher level degree in an S&E field of study. Of these 23.2 million individuals, the majority (17.3 million) held their highest level of degree (which can be a bachelor's, master's, professional, or doctorate) in an S&E field, the remainder held their highest level of degree in an S&E-related or non-S&E field. Of these S&E highest degrees, the most common fields were social sciences (6.8 million) and engineering (3.8 million). Computer and mathematical sciences (2.9 million), life sciences (2.8 million), and physical sciences (1.0 million) together were slightly less than the size of the social sciences component.

- Not all S&E degree holders work in jobs formally designated as S&E occupations. The number of college-educated individuals reporting that their jobs require at least a bachelor's degree level of technical expertise in S&E (19.4 million) is substantially higher than the number employed in S&E occupations (6.4 million), suggesting that the application of S&E knowledge and skills is widespread across the technologically sophisticated U.S. economy and not limited to jobs classified as S&E.

The S&E workforce has grown steadily over time.

- Between 1960 and 2015, the number of workers in S&E occupations grew at an average annual rate of 3%, compared with the 2% growth rate for the total workforce.
- During and immediately after the 2007-09 economic downturn, trends in S&E employment fared relatively better compared to overall employment trends. Between 2007 and 2010, S&E employment level remained stable whereas total employment declined. Both employment levels have risen since 2010.

S&E Workers in the Economy

Scientists and engineers work for all types of employers.

- The majority of scientists and engineers (individuals trained or employed in S&E) are employed in the business sector (71%), followed by the education (19%) and government (11%) sectors. Within the business sector, for-profit businesses employ the bulk of scientists and engineers.

- Among individuals with S&E doctorates, the proportion working in the business sector is 48%, and the proportion working in the education sector is 43%. Within the education sector, over 90% work in 4-year colleges and universities, including those in postdoctoral and other temporary positions.
- The majority of educational institutions and government entities that employ scientists and engineers are large employers (i.e., having 100 or more employees). In contrast, scientists and engineers working in the business sector are distributed across firms of different sizes.
- Within the business sector, the industry with the largest number of workers in S&E occupations is professional, scientific, and technical services.
- Employment in S&E occupations is geographically concentrated in the United States. The 20 metropolitan areas with the largest proportion of the workforce employed in S&E occupations in 2015 accounted for 19% of nationwide S&E employment, compared to 9% of all employment.

S&E Labor Market Conditions

Whether measured by S&E occupation or degree, S&E workers have higher earnings than other comparable workers.

- Half of the workers in S&E occupations earned $84,000 or more in 2016, which is more than double the median salaries ($37,000) of the total workforce.
- Employed college graduates with a highest degree in S&E earn more than those with non-S&E degrees (median salaries in 2015 were $68,000 and $55,000, respectively). For the most part, the earnings premium associated with an S&E degree is present across early, mid-, and later career stages.

The S&E labor force is less likely than others to experience unemployment.

- Unemployment rates for college-educated individuals in S&E occupations tend to be lower than those for all college graduates and much lower than those for the overall labor force: In February 2015, about 3.3% of scientists and engineers and 3.5% of all college-educated individuals in the labor force were unemployed, which are both substantially less than the official unemployment rate for the entire U.S. labor force (5.8%).
- Unemployment rates for S&E doctorate (2.6%) and master’s degree holders (2.8%) are even lower than those for S&E bachelor’s degree holders (4.0%).

Demographics of the S&E Workforce

Mirroring U.S. population trends, the S&E labor force is aging. Additionally, a larger proportion of older scientists and engineers remain in the labor force in 2015 than in 1993.

- The median age of scientists and engineers in the labor force was 43 years in 2015, compared to 41 years in 1995.
- Between 1993 and 2015, an increasing percentage of scientists and engineers in their 60s reported that they were still in the labor force. Whereas 54% of scientists and engineers between the ages of 60 and 69 were in the labor force in 1993, the comparable percentage rose to 62% in 2015.

Women remain underrepresented in the S&E workforce, but less so than in the past.

- In 2015, women constituted 50% of the college-educated workforce, 40% of employed individuals whose highest degree was in an S&E field, and 28% of those in S&E occupations. The corresponding 1993 shares were 43%, 30%, and 23%, respectively.
- Women employed in S&E occupations are concentrated in different occupational categories than men, with relatively high proportions in social sciences (60%) and life sciences (48%) and relatively low proportions in engineering (15%), physical sciences (28%), and computer and mathematical sciences (26%).

Historically underrepresented racial and ethnic groups, particularly blacks and Hispanics, continue to be part of the S&E workforce at rates lower than their presence in the U.S. population, whereas Asians and foreign-born individuals are represented in the S&E workforce at substantially higher rates.

- Hispanics, blacks, and American Indians or Alaska Natives together make up 27% of the U.S. population age 21 and older but a much smaller proportion of the S&E workforce: 15% of S&E highest degree holders and 11% of workers in S&E occupations.
- Conversely, Asians make up 6% of the U.S. population age 21 and older but account for 21% of those employed in S&E occupations. Asians have a large presence in engineering and computer sciences occupations, particularly among computer software and hardware engineers, software developers, computer and information research scientists, and postsecondary teachers in engineering.
- About 67% of workers in S&E occupations are non-Hispanic whites, which is comparable to their overall representation in the U.S. population age 21 and older (66%).
- Foreign-born individuals account for 29% of all workers in S&E occupations, which is substantially higher than their share of the entire college-educated workforce (17%).
- Foreign-born workers employed in S&E occupations tend to have higher levels of education than their U.S. native-born counterparts.

A variety of indicators point to a post-recession increase in the immigration of scientists and engineers following a temporary decline during the 2007–09 economic downturn.

- The issuance of new H-1B visas, which languished during the recession, continued to increase since 2009 and, by 2015, exceeded the pre-recession levels.
- About 70% of temporary visa holders earning a U.S. S&E doctorate are in the United States at least 5 years later. This proportion reached 67% in 2005, declined during the economic downturn, and then rose to 70% in 2015.

Global S&E Labor Force

Worldwide, the number of workers engaged in research has been growing. This includes “professionals engaged in the conception or creation of new knowledge" who "conduct research and improve or develop concepts, theories, models, techniques instrumentation, software or operational methods" (OECD 2015).

- Among countries with large numbers of researchers—defined as workers engaged in the conception or creation of new knowledge—growth since 2000 has been most rapid in China and South Korea.
- The United States and the European Union experienced steady growth but at lower rates than China or South Korea.

- Russia and, to some extent, Japan were exceptions to the worldwide trend. Between 2000 and 2014, the number of researchers in Japan rose very slightly; in Russia, the number declined.

Introduction

Chapter Overview

Policymakers and scholars emphasize innovation based on S&E R&D as a vehicle for a nation's economic growth and global competitiveness. In the increasingly interconnected world of the 21st century, workers with S&E expertise are integral to a nation's innovative capacity because of their high skill level, their creative ideas, and their ability not only to advance basic scientific knowledge but also to transform advances in fundamental knowledge into tangible and useful products and services. As a result, these workers make important contributions to improving the nation's living standards.

Chapter Organization

The U.S. S&E workforce includes both individuals employed in S&E occupations and individuals educated in S&E fields but employed in a variety of non-S&E occupations. Many more individuals have S&E degrees than work in S&E occupations. Indicative of a knowledge-based economy, many individuals in non-S&E occupations reported that their work nevertheless requires a bachelor's degree level of S&E expertise. Therefore, the first section in this chapter, U.S. S&E Workforce: Definition, Size, and Growth, discusses the S&E workforce based on three measures: workers in S&E occupations, holders of S&E degrees, and use of S&E technical expertise on the job. This section also discusses the interplay between educational background and choice of occupation.

The second section in this chapter, S&E Workers in the Economy, examines the distribution of S&E workers across employment sectors. It describes the distribution of S&E workers across sectors (e.g., business, education, government) as well as within particular sectors (e.g., local, state, and federal government). This section also presents data on geographic distribution of S&E employment in the United States. Data on R&D activity and work-related training by S&E workers are also discussed.

The third section, S&E Labor Market Conditions, looks at labor market outcomes for S&E workers. Data in this section focus on earnings and unemployment, with a focus on recent S&E graduates.

The next three sections cover workforce demographics. Age and Retirement of the S&E Workforce presents data on the age distribution and retirement patterns of S&E workers. Women and Minorities in the S&E Workforce focuses on S&E participation by women and by racial and ethnic minorities; this section also presents data on salary differences by sex and by race and ethnicity. Immigration and the S&E Workforce presents data on S&E participation by foreign-born individuals in the United States.

The final section in this chapter is Global S&E Labor Force. Although there are indications that the global S&E labor force has grown, international data on the characteristics of this broader labor force are particularly limited and are not always comparable with data for the United States. In this final section, data from the Organisation for Economic Co-operation and Development (OECD) are used to present indicators of worldwide R&D employment.

This chapter uses a variety of data sources, including, but not limited to, the National Science Foundation/National Center for Science and Engineering Statistics' (NSF/NCSES's) National Survey of College Graduates (NSCG), Survey of Doctorate

Recipients (SDR), Survey of Earned Doctorates (SED), and Survey of Graduate Students and Postdoctorates in Science and Engineering; the Census Bureau's American Community Survey (ACS); the Occupational Employment Statistics (OES) survey administered by the Bureau of Labor Statistics (BLS); and the Current Population Survey (CPS) sponsored jointly by the Census Bureau and BLS. Different sources cover different segments of the population and different levels of detail on the various topics. (See sidebar NSF/NCSES's Data on Scientists and Engineers and Table 3-1.) Although data collection methods and definitions can differ across surveys in ways that affect estimates, presenting data from different sources facilitates a more accurate and comprehensive picture of the very specialized S&E workforce. Long-term trends, international trends, and comparisons of S&E and non-S&E workers are discussed whenever data are available.

TABLE 3-1

Major sources of data on the U.S. labor force

(Data sources and information)

Data source	Data collection agency	Data years	Major topics	Respondent	Coverage
Occupational Employment Statistics (OES), https://www.bls.gov/oes/	Department of Labor, Bureau of Labor Statistics	Through 2016	Worker occupation, salary, industry, employer location (national, state, metropolitan statistical area)	Employing organizations	All full-time and part-time wage and salary workers in nonfarm industries; does not cover self-employed, owners and partners in unincorporated firms, household workers, or unpaid family workers
National Survey of College Graduates (NSCG), https://www.nsf.gov/statistics/srvygrads/; see sidebar NSF/NCSES's Data on Scientists and Engineers	National Science Foundation, National Center for Science and Engineering Statistics	Through 2015	Employment status, occupation, job characteristics (work activities, technical expertise), salary, detailed educational history, demographic characteristics	Individuals	Individuals with a bachelor's degree or higher in any field, including an oversample of individuals with a bachelor's degree or higher in an S&E or S&E-related field or with non-S&E degrees but working in an S&E or S&E-related occupation
Survey of Doctorate Recipients (SDR), https://www.nsf.gov/statistics/srvydoctoratework/; see sidebar NSF/NCSES's Data on Scientists and Engineers	National Science Foundation, National Center for Science and Engineering Statistics	Through 2015	Employment status, occupation, job characteristics (work activities, technical expertise), salary, detailed educational history, demographic characteristics	Individuals	Individuals with U.S.-awarded research doctorates (includes both U.S. and non-U.S. residents)
American Community Survey (ACS), https://www.census.gov/programs-surveys/acs/	Department of Commerce, Census Bureau	Through 2015	Employment status, occupation, educational attainment, demographic characteristics	Households	U.S. population
Current Population Survey (CPS), https://www.census.gov/cps/	Department of Labor, Bureau of Labor Statistics	Through 2015	Employment status, occupation	Households	Civilian noninstitutional population ages 16 or over

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U.S. S&E Workforce: Definition, Size, and Growth

Definition of the S&E Workforce

Because there is no standard definition of S&E workers, this section presents multiple categorizations for measuring the size of the S&E workforce.[1] In general, this section defines the S&E workforce to include people who either work in S&E occupations or hold S&E degrees. Because the application of S&E knowledge and skills is not limited to jobs classified as S&E, the number of workers reporting that their jobs require at least a bachelor's degree level of knowledge in one or more S&E fields exceeds the number of jobs in the economy with a formal S&E label. Therefore, this section also presents data on the use of S&E technical expertise on the job to provide an estimate of the S&E workforce. The estimated number of scientists and engineers varies based on the criteria applied to define the S&E workforce.

U.S. federal occupation data classify workers by the activities or tasks they primarily perform in their jobs. NSF and Census Bureau occupation data are based on information provided by individuals or household members and classified into categories based on the Standard Occupational Classification (SOC) system (see Appendix Table 3-1).[2] In contrast, the BLS-administered OES survey relies on employers to classify their workers using SOC definitions. Differences between employer- and individual-provided information can affect the content of occupation data.

NSF uses a set of SOC categories that it calls *S&E occupations*. Very broadly, these occupations include life scientists, computer and mathematical scientists, physical scientists, social scientists, and engineers. NSF also includes postsecondary teachers of these fields in S&E occupations. A second category of occupations, *S&E-related occupations*, includes health-related occupations, S&E managers, S&E technicians and technologists, architects, actuaries, S&E precollege teachers, and postsecondary teachers in S&E-related fields. The S&E occupations are generally assumed to require at least a bachelor's degree level of education in an S&E field. The vast majority of S&E-related occupations also require S&E knowledge or training, but an S&E bachelor's degree may not be a required credential for employment in some of these occupations. Examples include health technicians and computer network managers. Other occupations, although classified as *non-S&E occupations*, may include individuals who use S&E technical expertise in their work. Examples include technical writers who edit scientific publications and salespeople who sell specialized research equipment to chemists and biologists. The NSF occupational classification of S&E, S&E-related, and non-S&E occupations appears in ▦ Table 3-2, along with the NSF educational classification of S&E, S&E-related, and non-S&E degree fields.

TABLE 3-2

Classification of degree fields and occupations

(Classifications, fields, and occupations)

Classification	Degree field	Occupation	Occupation classification	
			STEM	S&T
S&E	Biological, agricultural, and environmental life sciences	Biological, agricultural, and environmental life scientists	X	X
	Computer and mathematical sciences	Computer and mathematical scientists	X	X
	Physical sciences	Physical scientists	X	X
	Social sciences	Social scientists	X	X
	Engineering	Engineers	X	X
	-	S&E postsecondary teachers		
S&E-related	Health fields	Health-related occupations		
	-	S&E managers	X	
	Science and math teacher education	S&E precollege teachers		
	Technology and technical fields	S&E technicians and technologists	X	X
	Architecture	Architects		
	Actuarial science	Actuaries		
	-	S&E-related postsecondary teachers		
Non-S&E	Management and administration	Non-S&E managers		
		Management-related occupations		
	Education (except science and math teacher education)	Non-S&E precollege teachers		
		Non-S&E postsecondary teachers		
	Social services and related fields	Social services occupations		
	Sales and marketing	Sales and marketing occupations		
	Arts and humanities	Arts and humanities occupations		
	Other fields	Other occupations		

S&T = science and technology; STEM = science, technology, engineering, and mathematics.

Note(s)

The designations STEM and S&T refer to occupations only. S&E occupations require at least a bachelor's degree in an S&E field of study, and S&E-related occupations require S&E knowledge or training but not necessarily at the bachelor's degree level. For more detailed classification of occupations and degrees by S&E, S&E-related, and non-S&E, see National Science Foundation, National Center for Science and Engineering Statistics, National Survey of College Graduates (NSCG), https://www.nsf.gov/statistics/srvygrads/.

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Indicative of a knowledge-based economy, the number of individuals who have S&E training or who reported applying S&E technical expertise in their jobs exceeds the number of individuals employed in jobs that are categorized as S&E. Therefore, a relatively narrow definition of the S&E workforce consists of workers in occupations that NSF designates as S&E occupations. In comparison, a much broader definition of an S&E worker, used by NSF's data on scientists and engineers, includes any individual with a bachelor's or higher level degree in an S&E or S&E-related field of study or a college graduate with a degree in any field employed in an S&E or S&E-related occupation.

As noted, the S&E workforce may also be defined by the technical expertise or training required to perform a job. Unlike information on occupational categories or educational credentials, information on the use of technical knowledge, skills, or expertise in a person's job reflects that individual's subjective opinion about the content and characteristics of the job.[3] The next section provides estimates of the size of the S&E workforce using these three definitions: those who work in S&E occupations, those who hold S&E degrees, and those whose jobs require S&E technical expertise.

Other general terms—including science, technology, engineering, and mathematics (STEM); science and technology (S&T); and science, engineering, and technology (SET)—are often used to designate the part of the labor force that works with S&E. These terms are broadly equivalent and have no standard definition.

SIDEBAR

NSF/NCSES's Data on Scientists and Engineers

The data on scientists and engineers from the National Center for Science and Engineering Statistics within the National Science Foundation provide detailed employment, education, and demographic information for scientists and engineers under age 76 residing in the United States. Scientists and engineers are defined as individuals who have college degrees in S&E or S&E-related fields or who have only a non-S&E degree at the bachelor's level or higher and are working in S&E or S&E-related occupations. (See Table 3-2 for definitions of S&E and S&E-related occupations.) Unless otherwise noted, this chapter uses the term "scientists and engineers" to refer to this broad definition and the term "college graduates" to refer to the population with at least a bachelor's degree. The data available on scientists and engineers are collected by two large demographic and workforce surveys of individuals conducted by NCSES: the National Survey of College Graduates (NSCG) and the Survey of Doctorate Recipients (SDR).

The NSCG and SDR provide the most comprehensive information about the size and characteristics of the S&E workforce. As a result, information obtained through these surveys is critically important to understand the education and employment patterns of scientists and engineers. Because the NSCG covers the entire population of college graduates residing in the United States, this survey provides information on individuals educated or employed in S&E fields as well as those educated or employed in non-S&E fields. The data presented in this chapter for all scientists and engineers and for all college graduates (regardless of S&E background) are mostly based on the NSCG.

Whereas NSCG data cover the general college-educated population, the SDR data provide information on scientists and engineers who earned their research doctoral degree in a science, engineering, or health (SEH) field from a U.S. academic institution. The SDR is a biennial survey that has been conducted since 1973; it is a unique source of information on educational and occupational achievements and career movements of the nation's doctoral scientists and engineers. Some data presented in this chapter for doctoral scientists and engineers are based on the SDR.

In prior editions of *Science and Engineering Indicators*, an integrated data system, the Scientists and Engineers Statistical Data System (SESTAT), was used as the main source of data within this chapter. SESTAT was formed through the integration of the NSCG, SDR, and the National Survey of Recent College Graduates (NSRCG), with the NSRCG providing data on recent bachelor's and master's degree recipients in S&E fields.

Recent sample design improvements to the NSCG increased the survey's population coverage of recent college graduates and eliminated the need for the NSRCG. In addition, the SDR recently expanded its sample to allow for the evaluation of employment characteristics at the fine field of study level for the first time. These recent survey changes provided an opportunity to use the NSCG and SDR data individually for this chapter.

Size of the S&E Workforce

When defined by occupation only, the S&E workforce totals approximately 6.7 million people according to the most recent estimates (Table 3-3). Those in S&E occupations who had at least a bachelor's degree are estimated at between 5.0 million and 6.4 million.[4] By far the largest categories of S&E occupations are in computer and mathematical sciences and in engineering, which together account for about 76% (among college-educated workers) to 85% (among workers of all education levels) of all employed workers in S&E occupations (Figure 3-1). Occupations in life, social, and physical sciences each employ a smaller proportion of S&E workers.

TABLE 3-3

Measures and size of U.S. S&E workforce: 2015 and 2016

(Number)

Measure	Education coverage	Data source	Individuals
Occupation			
Employed in S&E occupations	All education levels	2016 BLS OES survey	6,747,000
Employed in S&E occupations	Bachelor's and above	2015 NSF/NCSES NSCG	6,407,000
Employed in S&E occupations	All education levels	2015 Census Bureau ACS	6,703,000
Employed in S&E occupations	Bachelor's and above	2015 Census Bureau ACS	5,036,000
Education			
At least one degree in S&E field	Bachelor's and above	2015 NSF/NCSES NSCG	23,160,000
Highest degree in S&E field	Bachelor's and above	2015 NSF/NCSES NSCG	17,289,000
Job closely related to highest degree	Bachelor's and above	2015 NSF/NCSES NSCG	6,437,000
S&E occupation	Bachelor's and above	2015 NSF/NCSES NSCG	3,445,000
Other occupation	Bachelor's and above	2015 NSF/NCSES NSCG	2,993,000
Job somewhat related to highest degree	Bachelor's and above	2015 NSF/NCSES NSCG	4,148,000
S&E occupation	Bachelor's and above	2015 NSF/NCSES NSCG	1,122,000
Other occupation	Bachelor's and above	2015 NSF/NCSES NSCG	3,026,000
Job requires S&E technical expertise at bachelor's level			
In one or more S&E fields	Bachelor's and above	2015 NSF/NCSES NSCG	19,366,000
Engineering, computer science, mathematics, or natural sciences	Bachelor's and above	2015 NSF/NCSES NSCG	14,140,000
Social sciences	Bachelor's and above	2015 NSF/NCSES NSCG	8,919,000

ACS = American Community Survey; BLS = Bureau of Labor Statistics; NSCG = National Survey of College Graduates; NSF/NCSES = National Science Foundation, National Center for Science and Engineering Statistics; OES = Occupational Employment Statistics.

Note(s)

Estimates of the S&E workforce vary across the example surveys because of differences in the scope of the data collection (the NSCG collects data from individuals with bachelor's degrees and above only); because of the survey respondent (the NSCG collects data from individuals, the OES survey collects data from establishments, and the ACS collects data from households); or because of the level of detail collected on an occupation, which aids in classifying a reported occupation into a standard occupational category. All of these differences can affect the estimates. For example, the NSCG estimate of the number of workers in S&E occupations includes postsecondary teachers of S&E fields; however, postsecondary teachers in ACS are grouped under a single occupation code, regardless of field, and are therefore not included in the ACS estimate of the number of workers in S&E occupations. The totals for at least one degree in S&E field and highest degree in S&E field include individuals who are employed as well as those who are unemployed and out of the labor force.

Source(s)

BLS, OES survey (2016); Census Bureau, ACS (2015); NSF/NCSES, NSCG (2015), https://www.nsf.gov/statistics/srvygrads/.

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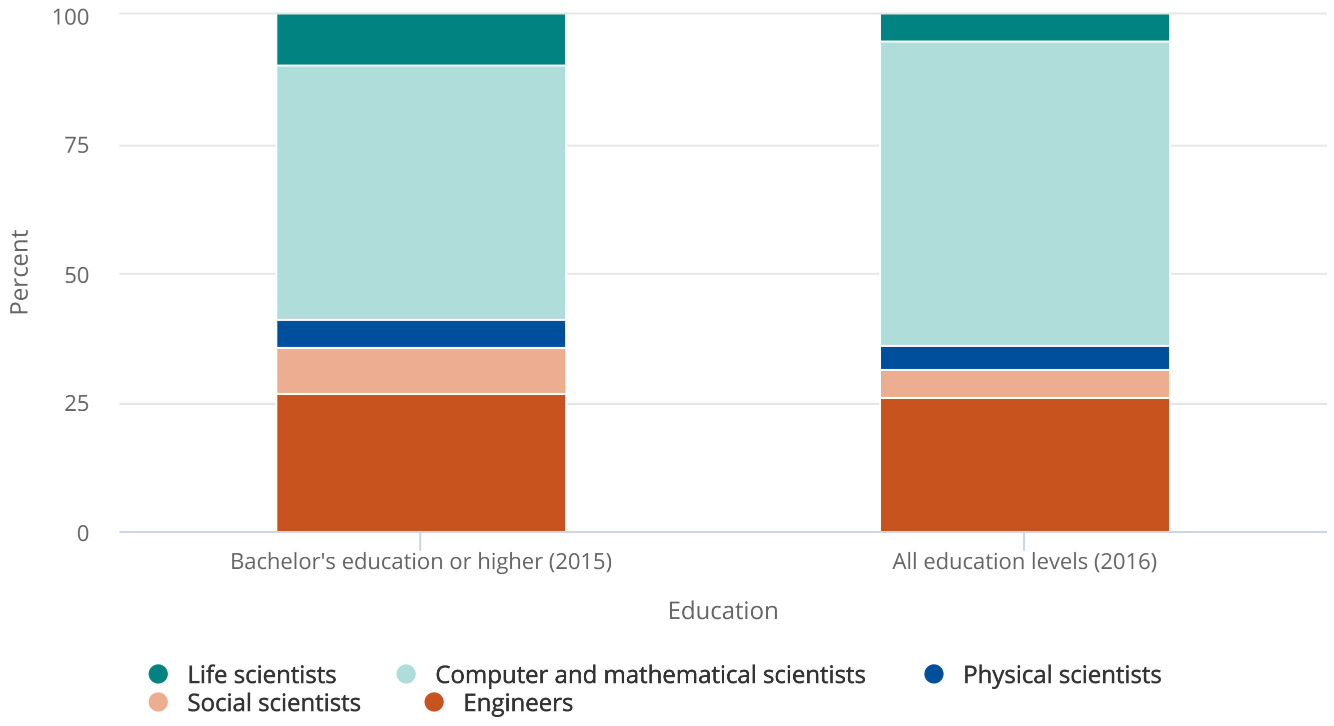
FIGURE 3-1

Employment in S&E occupations, by broad occupational category: 2015 and 2016



Source(s)

Bureau of Labor Statistics, Occupational Employment Statistics (OES) Survey (2016); National Science Foundation, National Center for Science and Engineering Statistics, National Survey of College Graduates (NSCG) (2015), https://www.nsf.gov/statistics/srvygrads/.

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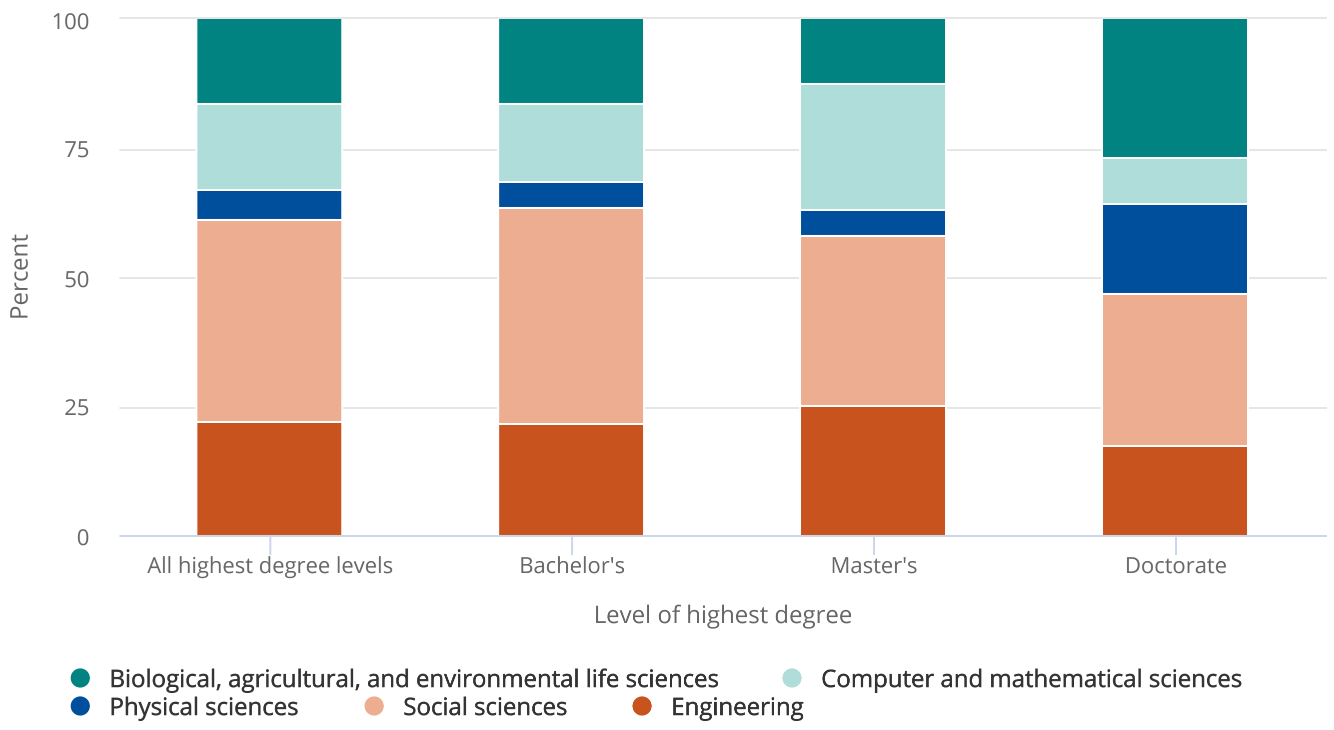
As noted earlier, S&E degree holders greatly outnumber those currently employed in S&E occupations. In 2015, about 23 million college graduates in the United States had a bachelor's or higher level degree in an S&E field of study (Table 3-3). About three-fourths of these college graduates (17.3 million) attained their highest degree—a bachelor's, master's, professional, or doctorate—in an S&E field (in this chapter, these individuals are referred to as *S&E highest degree holders*). An individual's highest degree is often an accurate representation of the skills and credentials that one employs in the labor market, which is why the data presented in this chapter by educational attainment are generally provided for highest degree. Overall, across all S&E highest degrees, social sciences and engineering were the most common degree fields (Figure 3-2).[5] The 17.3 million college graduates with an S&E highest degree includes 12.4 million with bachelor's degrees, 3.7 million with master's degrees, 1.2 million with doctorates, and 37,000 with professional degrees.

FIGURE 3-2

S&E degrees among college graduates, by field and level of highest degree: 2015



Note(s)

All highest degree levels includes professional degrees not shown separately.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Survey of College Graduates (NSCG) (2015), https://www.nsf.gov/statistics/srvygrads/.

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A majority of S&E degree holders (61%) reported that their job was either closely or somewhat related to their field of highest degree (▦Table 3-3). Because many of these individuals were employed in occupations not categorized as S&E, this suggests that the application of S&E knowledge and skills is widespread across the U.S. economy and not limited to occupations classified as S&E.

The extensive use of S&E expertise in the workplace is also evident from the number of college graduates who indicate that their job requires technical expertise at the bachelor's degree level in S&E fields. Nearly 19.4 million college graduates, regardless of field of degree or occupation, reported that their jobs required at least this level of technical expertise in one or more S&E fields (▦Table 3-3); this figure is three times as large as the 6.4 million college graduates employed in S&E occupations.

Growth of the S&E Workforce

The S&E workforce has grown faster over time than the overall workforce. According to Census Bureau data, employment in S&E occupations grew from about 1.1 million in 1960 to about 6.7 million in 2015 (Figure 3-3).[6] This represents an average annual growth rate of 3%, compared to a 2% growth rate in total employment during this period. S&E occupational employment as a share of total employment doubled, from about 2% in 1960 to about 4% in 2015. See sidebar Projected Growth of Employment in S&E Occupations for BLS data on occupational projections for the period 2014–24.

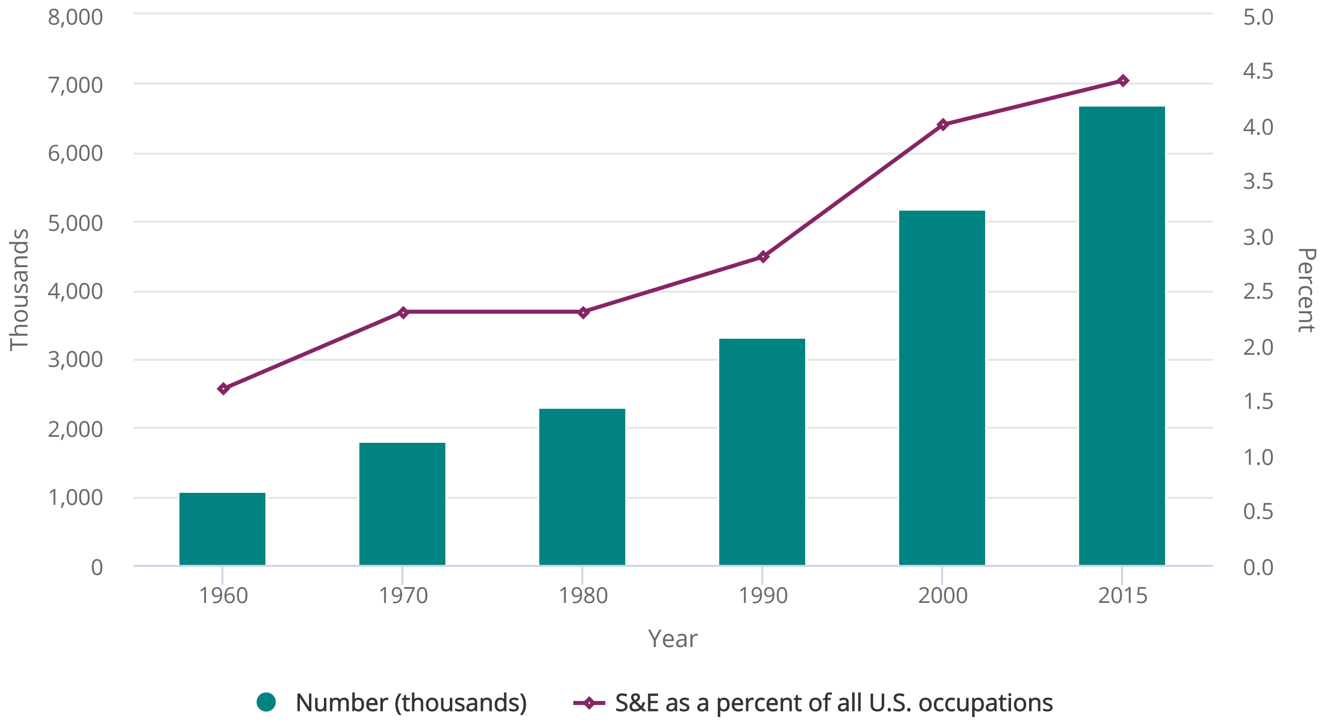
Data indicate that trends in S&E employment fared relatively better than overall employment trends during and after the 2007–09 economic downturn. Occupation-based estimates from BLS indicate that the size of the S&E workforce stayed relatively steady between May 2007 (5.6 million) and May 2010 (5.5 million) and then rose to 6.7 million by May 2016. The broader STEM workforce—including S&E technicians and managers—by May 2016 had increased to 8.7 million from 7.6 million in May 2007. The total workforce fell by 7.3 million between May 2007 (134 million) and May 2010 (127 million) and then rose to 140 million by May 2016.

The growth in the number of individuals with S&E degrees in recent years can be examined using NSF survey data on scientists and engineers. The total number of S&E highest degree holders employed in the United States grew from 9.6 million to 13.5 million between 2003 and 2015, reflecting a 2.9% annual average growth rate. Most broad S&E degree fields exhibited growth (Figure 3-4). (See Chapter 2 for a fuller discussion of S&E degrees.)

A number of factors have contributed to the growth in the S&E labor force over time: the rising demand for S&E skills in a global and highly technological economic landscape; increases in U.S. S&E degrees earned by women, racial and ethnic minority groups, and foreign-born individuals; temporary and permanent migration to the United States of those with foreign S&E educations; and the rising number of scientists and engineers who are delaying their retirement. The demographic sections of this chapter provide data on aging and retirement patterns of scientists and engineers as well as on S&E participation by women, racial and ethnic minorities, and foreign-born individuals.

FIGURE 3-3

Individuals employed in S&E occupations in the United States: Selected years, 1960–2015



Note(s)

Data include people at all education levels.

Source(s)

Census Bureau, Decennial Census (1960–2000), and American Community Survey (ACS) (2015) microdata, downloaded from the Integrated Public Use Microdata Series (IPUMS), University of Minnesota, https://www.ipums.org.

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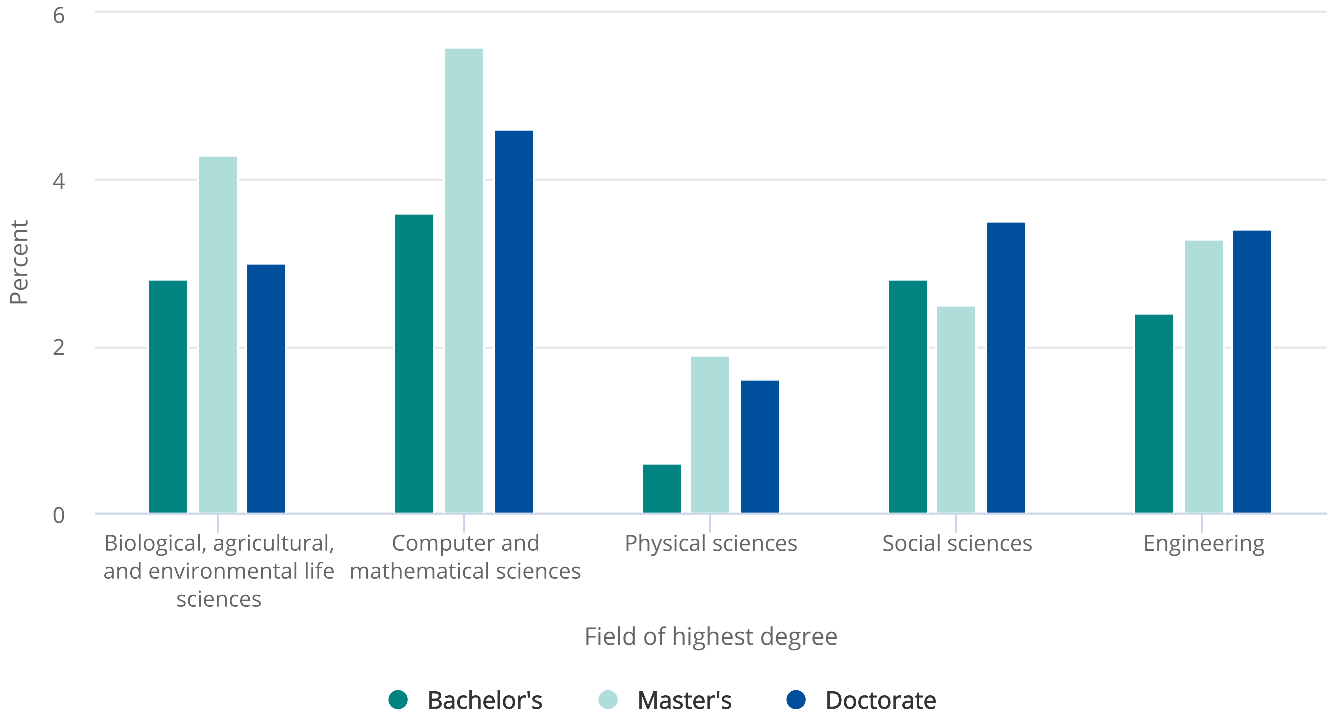
FIGURE 3-4

Average annual growth in the total number of employed individuals with highest degree in S&E, by field and level of highest degree: 2003–15



Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Scientists and Engineers Statistical Data System (SESTAT) (2003), https://www.nsf.gov/statistics/sestat/, and National Survey of College Graduates (NSCG) (2015), https://www.nsf.gov/statistics/srvygrads/.

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SIDEBAR

Projected Growth of Employment in S&E Occupations

This sidebar presents the most recent data from the Bureau of Labor Statistics (BLS) on occupation projections for the period 2014–24. While interpreting the data, readers should keep in mind that employment projections are uncertain. Many industry and government decisions that affect hiring are closely linked to national and global fluctuations in aggregate economic activity, which are difficult to forecast long in advance. In addition, technological and other innovations will influence demand for workers in specific occupations. The assumptions underlying projections are sensitive to fundamental empirical relationships and, as a result, may become less accurate as overall economic conditions change.*

BLS occupational projections for the period 2014–24 suggest that total employment in occupations that NSF classifies as S&E will increase at a faster rate (11%) than employment in all occupations (7%) (Table 3-A; Figure 3-A; Appendix Table 3-2). These projections are based only on the demand for narrowly defined S&E occupations and do not include the wider range of occupations in which S&E degree holders often use their training.

Job openings include both new jobs and openings caused by existing workers permanently leaving the occupations. During the period 2014–24, job openings in NSF-identified S&E occupations are projected to represent nearly one-third (30%) of current employment in 2014, which is similar to the proportion of job openings in all occupations (31%) (Figure 3-B).

TABLE 3-A

Bureau of Labor Statistics projections of employment and job openings in S&E and other selected occupations: 2014–24

(Thousands)

Occupation	BLS National Employment Matrix 2014 estimate	BLS projected 2024 employment	Job openings from growth and net replacements, 2014–24	10-year growth in total employment (%)	10-year job openings as percentage of 2014 employment
All occupations	150,540	160,329	46,507	6.5	30.9
All S&E	6,262	6,957	1,881	11.1	30.0
Computer and mathematical scientists	3,714	4,268	1,064	14.9	28.6
Life scientists	311	330	117	6.1	37.5
Physical scientists	297	317	93	6.7	31.2
Social scientists	304	341	97	12.4	31.9
Engineers	1,636	1,701	511	4.0	31.2
S&E-related occupations					
S&E managers	919	1,034	308	12.5	33.5
S&E technicians and technologists	1,158	1,172	335	1.2	28.9
Computer programmers	329	302	81	-8.0	24.7
Health care practitioners and technicians	8,237	9,585	3,162	16.4	38.4
Selected other occupations					
Postsecondary teachers	1,869	2,089	551	11.7	29.5
Lawyers	779	823	158	5.6	20.3

BLS = Bureau of Labor Statistics.

Note(s)

Estimates of current and projected employment for 2014–24 are from BLS's National Employment Matrix; data in the matrix are from the Occupational Employment Statistics (OES) survey and the Current Population Survey (CPS). Together, these sources cover paid workers, self-employed workers, and unpaid family workers in all industries, agriculture, and private households. Because data are derived from multiple sources, they can often differ from employment data provided by the OES survey, CPS, or other employment surveys alone. BLS does not make projections for S&E occupations as a group nor does it do so for some of the S&E and S&E-related occupational categories as defined by the National Science Foundation (NSF); numbers in the table are based on the sum of BLS projections for occupations that the NSF includes in the respective categories. See Appendix Table 3-2.

Source(s)

BLS, Employment Projections program, 2014–24, special tabulations of 2014–24 Employment Projections.

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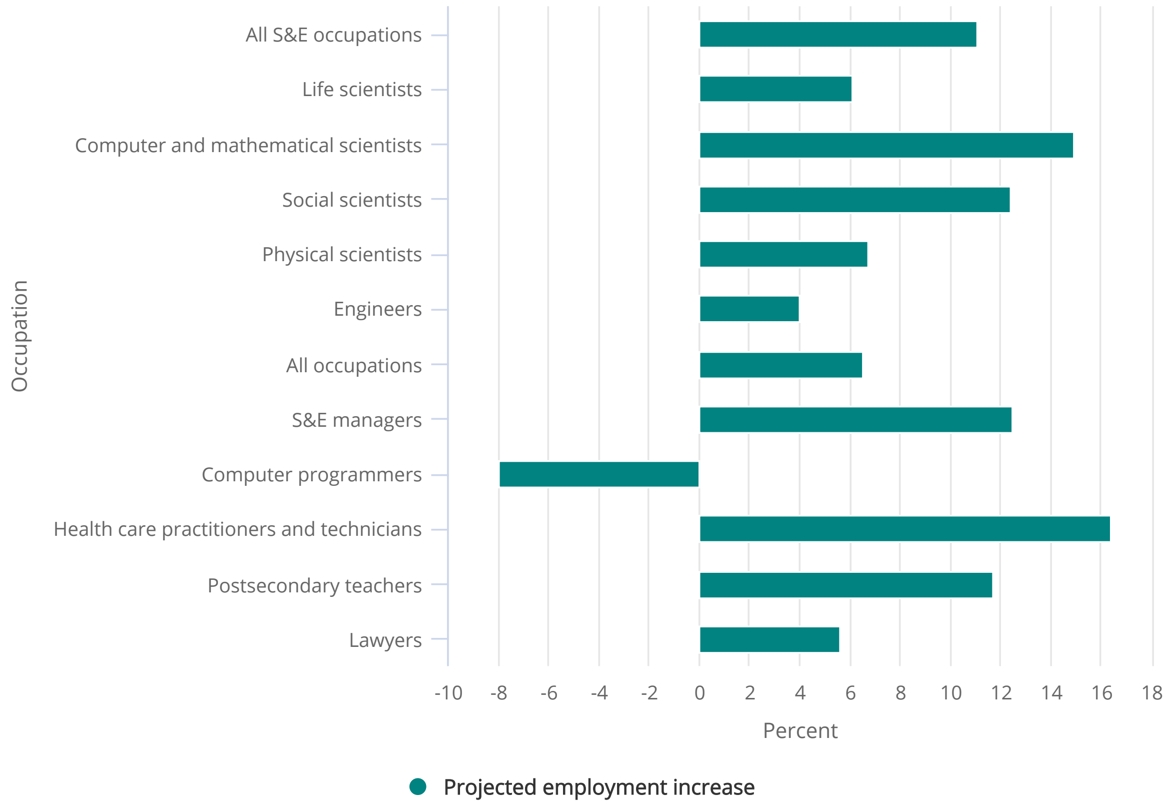
FIGURE 3-A

Projected increases in employment for S&E and other selected occupations: 2014–24



Source(s)

Bureau of Labor Statistics, Employment Projections program, special tabulations (2015) of 2014–24 Employment Projections, https://www.bls.gov/emp/. See Appendix Table 3-2.

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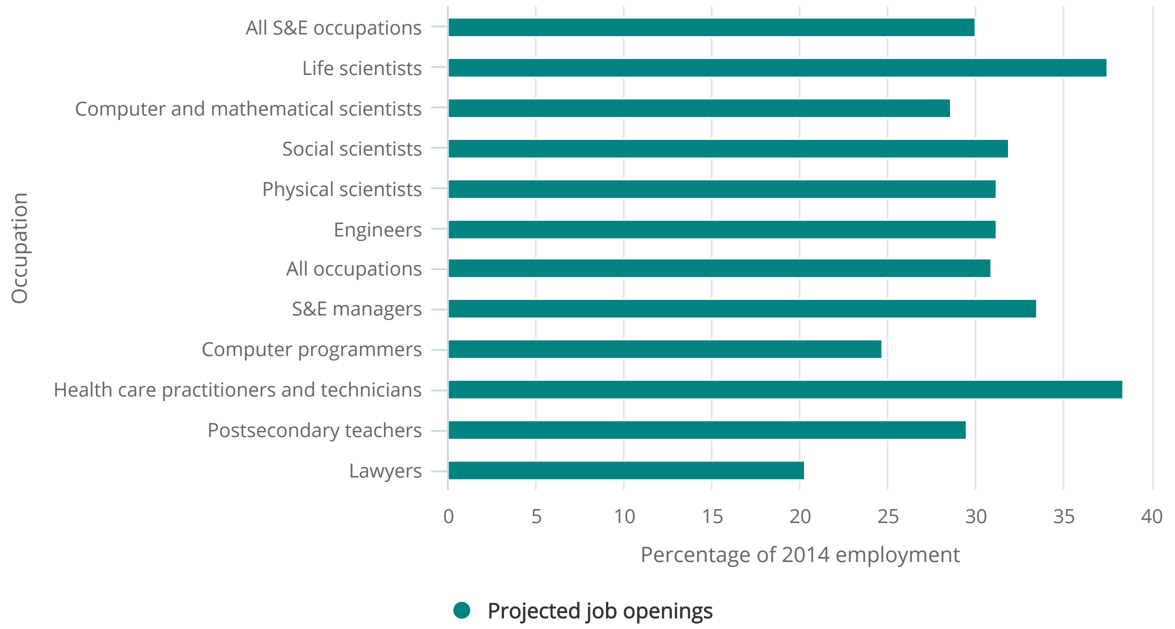
FIGURE 3-B

Projected job openings in S&E and other selected occupations: 2014–24



Source(s)

Bureau of Labor Statistics, Employment Projections program, special tabulations (2015) of 2014–24 Employment Projections, https://www.bls.gov/emp/. See Appendix Table 3-2.

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Of the BLS-projected net job openings in NSF-identified S&E occupations, the majority (57%) are projected to be in computer and mathematical sciences occupations, the largest subcategory of S&E occupations (Table 3-A). This occupational group also has the largest projected growth rate (15%) among NSF-identified S&E groups. Engineering occupations, the second largest subcategory of S&E occupations, are expected to generate about one-fourth (27%) of all job openings in S&E occupations during the period 2014–24; however, the growth rate in these occupations (4%) is projected to be lower than the growth rate for all occupations (7%). The other broad categories of S&E occupations—life sciences, social sciences, and physical sciences occupations—account for much smaller proportions of S&E occupations and are projected to have a growth rate between 6% and 12%. Job openings in the broad categories of S&E occupations are projected to represent relatively similar proportions of current employment in their respective fields, ranging from 29% to 38%.

In addition to S&E occupations, Table 3-A also shows S&E-related and selected other occupations that include significant numbers of S&E-trained workers. Among these occupations, the health care practitioners and technicians group, which employs more workers than all S&E occupations combined, is projected to grow 16%, more than double the growth rate for all occupations. The postsecondary teachers group, which includes all fields of instruction, and the S&E

managers group are projected to grow 12% and 13%, respectively, both of which are slightly higher than the 11% projected growth rate for all S&E occupations. In contrast, BLS projects that the computer programmers group and the S&E technicians and technologists group will grow more slowly than all S&E occupations, with the computer programmers group declining in number during this time period.

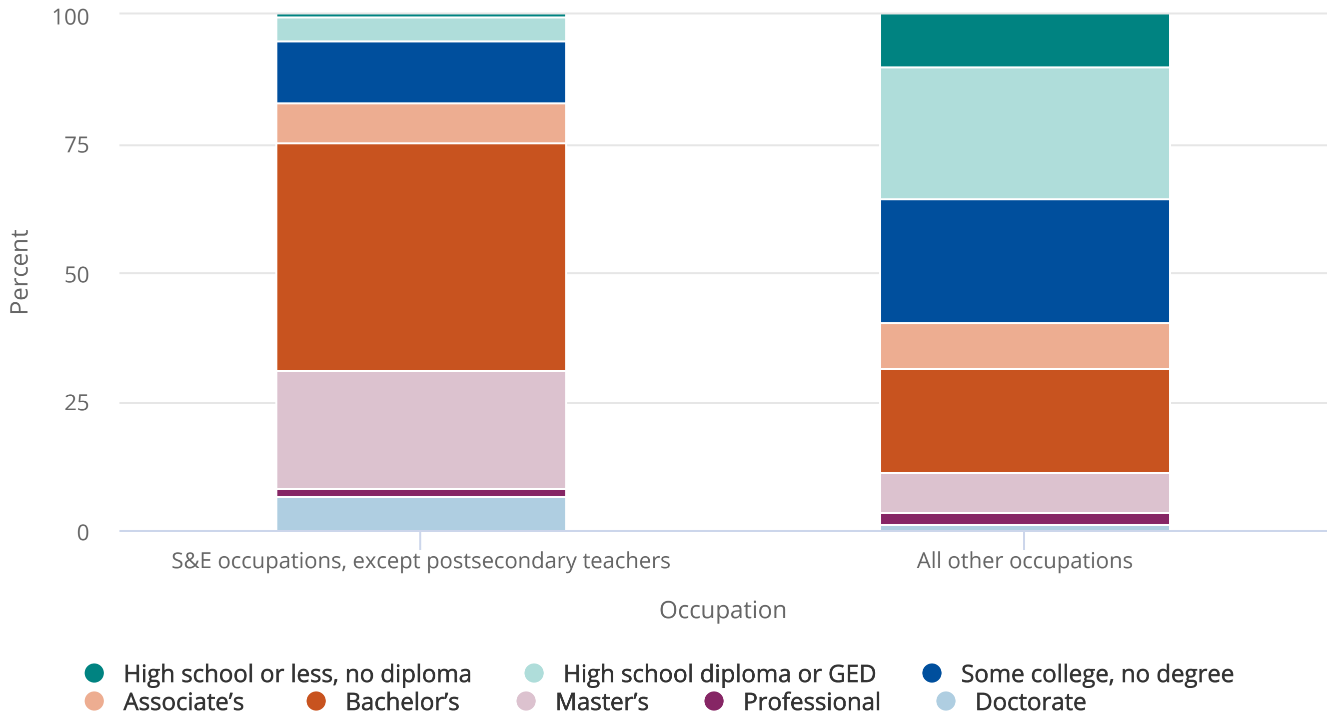
* The mean absolute percentage error in the 1996 BLS projection of 2006 employment in detailed occupations was 17.6% (Wyatt 2010). The inaccuracies in the 1996 projection of 2006 employment were primarily the result of not anticipating the housing bubble or increases in oil prices (Wyatt 2010).

Educational Distribution of Workers in S&E Occupations

Workers in S&E occupations have undergone more formal training than the general workforce (Figure 3-5). Data from the 2015 ACS indicate that a larger proportion of workers in S&E occupations (75%) (which in the ACS excludes postsecondary teachers) hold a bachelor's or higher degree than workers in all other occupations (31%).[7] The proportion of workers with advanced degrees beyond the bachelor's level is 31% in S&E occupations, compared to 11% in all other occupations. About 7% of all S&E workers (again excluding postsecondary teachers) have doctorates.

FIGURE 3-5

Educational attainment, by type of occupation: 2015



GED = General Equivalency Diploma.

Source(s)

Census Bureau, American Community Survey (ACS) (2015).

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Compared with the rest of the workforce, very few of those employed in S&E occupations have only a high school degree. However, many individuals enter the S&E workforce with marketable technical skills from technical or vocational schools (with or without an earned associate's degree) or college courses; some also acquire these skills through workforce experience or on-the-job training. In information technology—and, to some extent, in other occupations—employers frequently use certification examinations, not formal degrees, to judge skills. (See sidebar A Broader Look at the S&E Workforce and the discussion of community college in the Chapter 2 section Institutions Providing S&E Education.)

Formal S&E training is the usual pathway into S&E occupations. According to the 2015 NSCG, the vast majority (83%) of college graduates employed in S&E occupations have at least a bachelor's degree in an S&E field (Table 3-4). However, the prevalence of a degree in the same broad field as one's S&E occupation varies across occupational categories. For example, among computer and mathematical scientists, less than one-half (45%) have a bachelor's or higher level degree in a field of study that is equivalent to the field in which they work, and about one-fifth (21%) have no degree in any S&E or S&E-related field of study. In contrast, 76% of life scientists, 76% of physical scientists, 81% of social scientists, and 81% of engineers have a bachelor's or higher level degree in their respective broad field. The next section presents data on the proportion of S&E degree holders who are employed in S&E and non-S&E occupational categories.

TABLE 3-4

Educational background of college graduates employed in S&E occupations, by broad S&E occupational category: 2015

(Percent)

Educational background	All S&E occupations	Biological, agricultural, and environmental life scientists	Computer and mathematical scientists	Physical scientists	Social scientists	Engineers
Total (number)	6,407,000	631,000	3,156,000	331,000	570,000	1,719,000
At least one S&E degree	82.8	88.6	75.0	97.6	86.5	91.1
At least one S&E degree in field	62.4	76.1	44.8	75.5	80.9	81.0
Highest degree in field	75.8	66.9	40.6	70.1	70.2	74.5
All degrees in S&E	71.0	71.5	65.0	90.3	58.6	82.4
No S&E degrees but at least one S&E-related degree	4.3	5.7	4.4	1.5	2.5	4.6
No S&E or S&E-related degree but at least one non-S&E degree	12.9	5.7	20.6	0.9	11.1	4.3

Note(s)

At least one S&E degree in field is the proportion of workers in a particular S&E occupational category with at least one bachelor's or higher level degree in the same broad field. Highest degree in field is the proportion of workers in a particular S&E occupational category with highest degree in the same broad field. For example, among computer and mathematical scientists, these data refer to the proportion with at least one bachelor's or higher level degree in the broad field of computer and mathematical sciences and the proportion with highest degree in the broad field of computer and mathematical sciences, respectively. Detail may not add to total because of rounding.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Survey of College Graduates (NSCG) (2015), https://www.nsf.gov/statistics/srvygrads/.

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Occupational Distribution of S&E Degree Holders and the Relationship between Jobs and Degrees

Using data from the NSCG, which provides information on both degree achievement and occupational employment of scientists and engineers in the United States, this section analyzes the interplay between degree and occupation for individuals who earned a highest degree in an S&E discipline and those who earned a highest degree in a non-S&E discipline.

Although an S&E degree is often necessary to obtain S&E employment, many individuals with S&E degrees pursue careers in non-S&E fields. However, most workers with S&E training who work in non-S&E jobs reported that their work is related to their S&E training, suggesting that the application of S&E skills and expertise extends well beyond jobs formally classified as S&E occupations. (The section S&E Workers in the Economy provides data on R&D activity of scientists and engineers employed in S&E and non-S&E occupations.)

Only about half of those with a highest degree in S&E are employed in an S&E (36%) or S&E-related (15%) occupation; the other 50% are employed in non-S&E occupations. Figure 3-6 shows the occupational distribution of the S&E workforce with S&E, S&E-related, and non-S&E highest degrees. The largest category of non-S&E jobs for these S&E degree holders is management and management-related occupations (2.5 million workers), followed by sales and marketing (1.1 million workers) (the non-S&E category “Other non-S&E occupations” has a larger total of S&E degree holders, however, it includes a wide variety of non-S&E occupations) (Appendix Table 3-3). Other non-S&E occupations with a large number of S&E-trained workers include social services (429,000) and college and precollege teaching in non-S&E areas (404,000). S&E degree holders also work in S&E-related jobs such as health (666,000), S&E management (477,000), S&E technician or technologist (506,000), and precollege teaching in S&E areas (269,000).

Most individuals with a highest degree in S&E but working in non-S&E occupations still see S&E technical expertise as relevant to their jobs. Most indicate that their jobs are either closely (35%) or somewhat (35%) related to their highest degree field (Table 3-5). A distinctive feature of the U.S. workforce is the multiple pathways that S&E workers take from degree to profession. The National Science Board reports that “[S&E] knowledge and skills enable multiple, dynamic pathways to [S&E] and non-[S&E] occupations alike.” (NSB 2015) For example, among S&E degree holders in non-S&E management and management-related occupations, about three-quarters indicate that their jobs are either closely (31%) or somewhat (43%) related to their S&E degree. Among those in social services and related occupations, these numbers are higher (91%); among those in sales and marketing, these numbers are lower (51%).

TABLE 3-5

Relationship of highest degree to job among S&E highest degree holders not in S&E occupations, by degree level: 2015

(Percent)

Highest degree	Degree related to job (%)		
	Closely	Somewhat	Not
All degree levels	34.6	35.0	30.4
Bachelor's	29.9	36.3	33.7
Master's	50.2	30.2	19.7
Doctorate	47.4	36.3	16.4

Note(s)

All degree levels includes professional degrees not broken out separately. Detail may not add to total because of rounding.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Survey of College Graduates (NSCG) (2015), https://www.nsf.gov/statistics/srvygrads/, and the Survey of Doctorate Recipients (SDR) (2015), https://www.nsf.gov/statistics/srvydoctoratework/.

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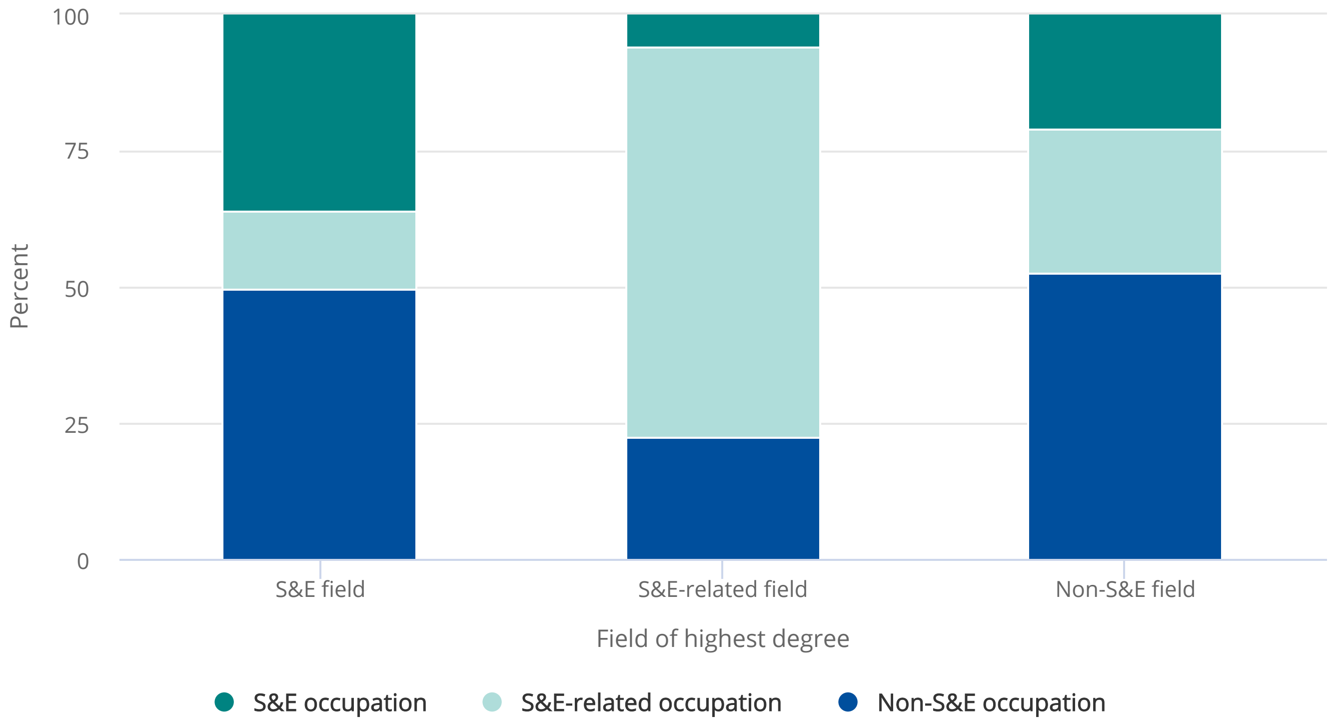
Unlike individuals with an S&E highest degree, at least half of those whose highest degrees are either in S&E-related or non-S&E fields are employed in their corresponding broad occupational categories (Figure 3-6). For those with an S&E-related highest degree, the largest category of jobs is health occupations (3.7 million); for those with a non-S&E highest degree, the largest category of jobs is non-S&E management and management-related occupations (1.0 million) (Appendix Table 3-3). Significant numbers of individuals with a non-S&E highest degree work in computer and information sciences (731,000), health-related occupations (532,000), and precollege teaching in S&E areas (526,000) or as lawyers or judges (594,000).

The pattern of a large proportion of individuals with a highest degree in S&E being employed in areas other than S&E occupations has been robust over time. Data from 1993 indicate that 36% of all scientists and engineers with S&E highest degrees were employed in S&E occupations, and the rest held positions in areas other than S&E. The comparable proportion in 2015 was also 36% (Figure 3-6).

FIGURE 3-6

Occupational distribution of scientists and engineers, by broad field of highest degree: 2015



Note(s)

Scientists and engineers include those with one or more S&E or S&E-related degrees at the bachelor's level or higher or those who have only a non-S&E degree at the bachelor's level or higher and are employed in an S&E or S&E-related occupation.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Survey of College Graduates (NSCG) (2015), https://www.nsf.gov/statistics/srvygrads/.

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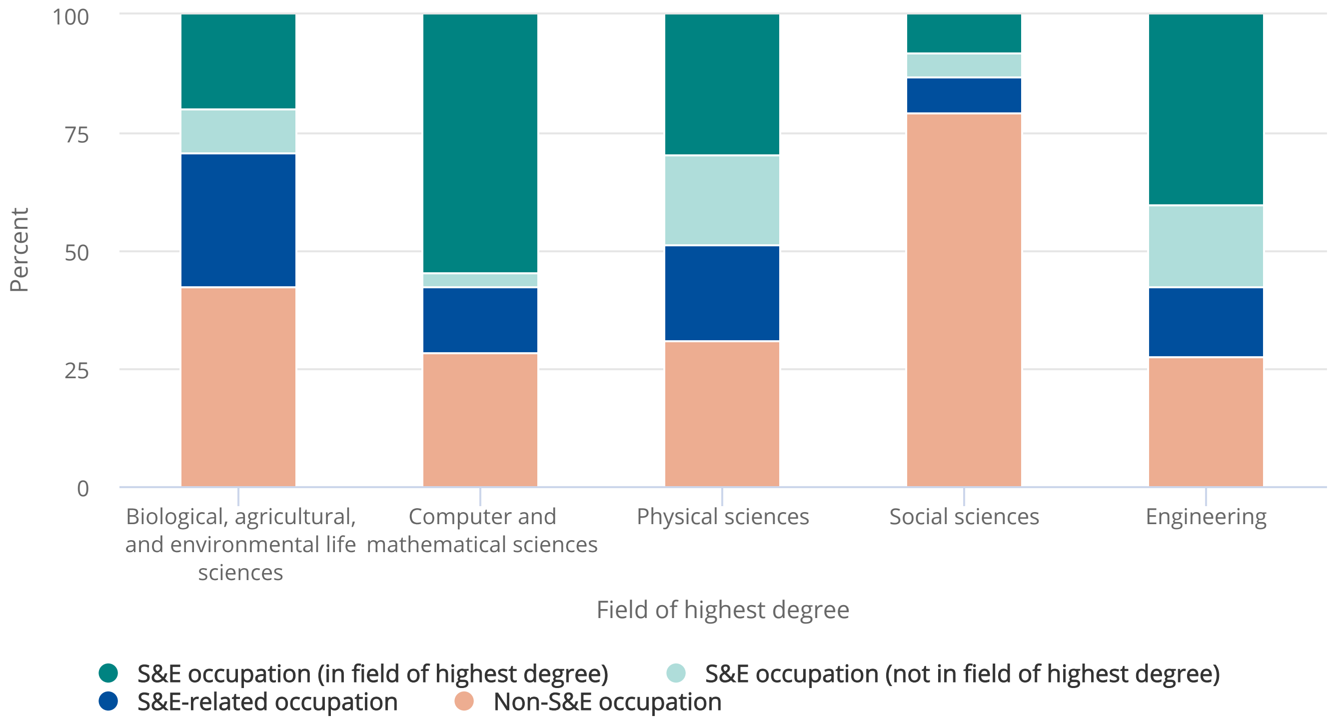
The proportion of S&E highest degree holders who go on to work in S&E occupations varies substantially by S&E degree fields and level of degree. Overall, this proportion is heavily influenced by individuals with social sciences degrees, who are the least likely to work in S&E occupations (13%); these individuals work primarily in non-S&E occupations (79%) (Figure 3-7) such as non-S&E management and management-related occupations, sales and marketing, and social services and related occupations including clergy, counselors, and social workers. In contrast, at least half of individuals with a highest degree in computer and mathematical sciences (58%), physical sciences (49%), or engineering (58%) reported working in S&E occupations. This general pattern between study field of degrees and occupations is similar at the bachelor's and master's degree levels but not at the doctoral level (Figure 3-8), where S&E doctorate holders most often work in an S&E occupation similar to their doctoral field.

FIGURE 3-7

Occupational distribution of S&E highest degree holders, by field of highest degree: 2015



Note(s)

Detail may not add to total because of rounding. For each broad S&E highest degree field, S&E occupation (in field of highest degree) includes individuals who report being employed in an occupation in the same broad category. For example, for highest degree holders in computer and mathematical sciences, S&E occupation (in field of highest degree) includes those who report the broad field of computer and mathematical sciences as their occupation, and S&E occupation (not in field of highest degree) includes those who report an S&E occupation other than computer and mathematical sciences occupations.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Survey of College Graduates (NSCG) (2015), https://www.nsf.gov/statistics/srvygrads/.

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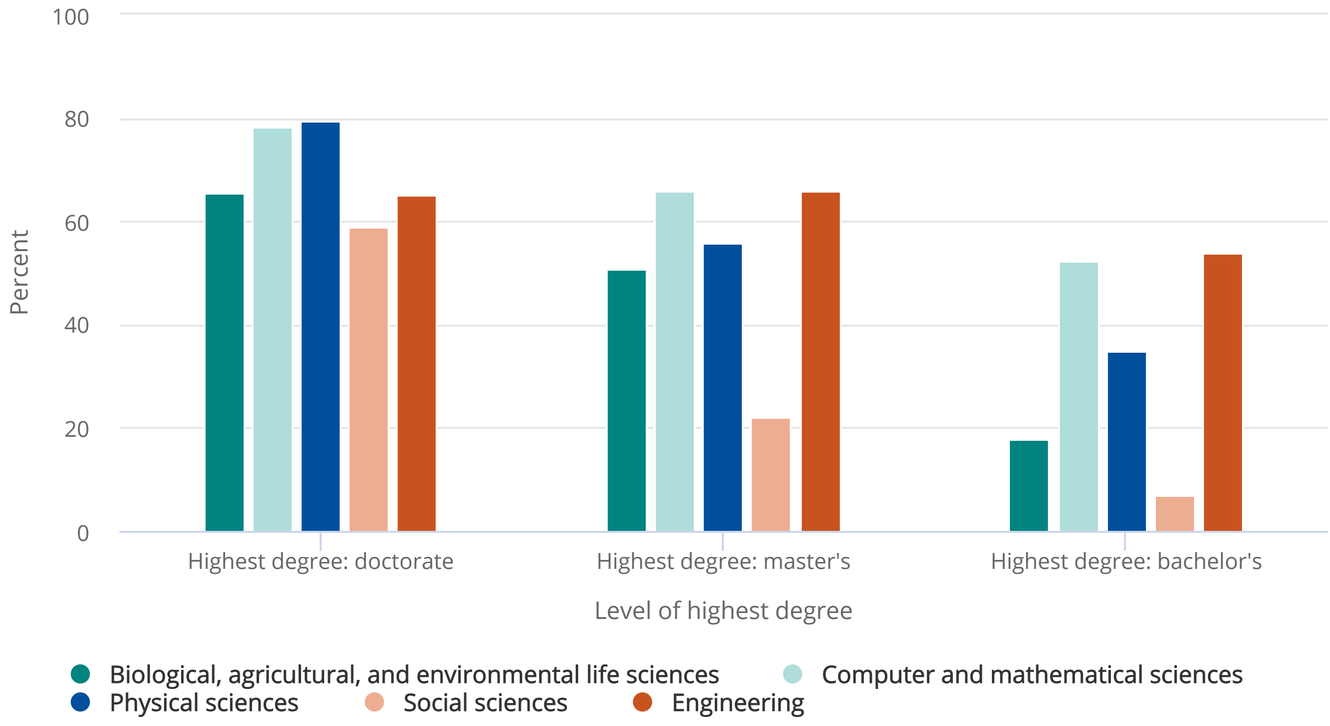
FIGURE 3-8

S&E degree holders working in S&E occupations, by level and field of S&E highest degree: 2015



Note(s)

Individuals may have degrees in more than one S&E degree field.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Survey of College Graduates (NSCG) (2015), https://www.nsf.gov/statistics/srvygrads/.

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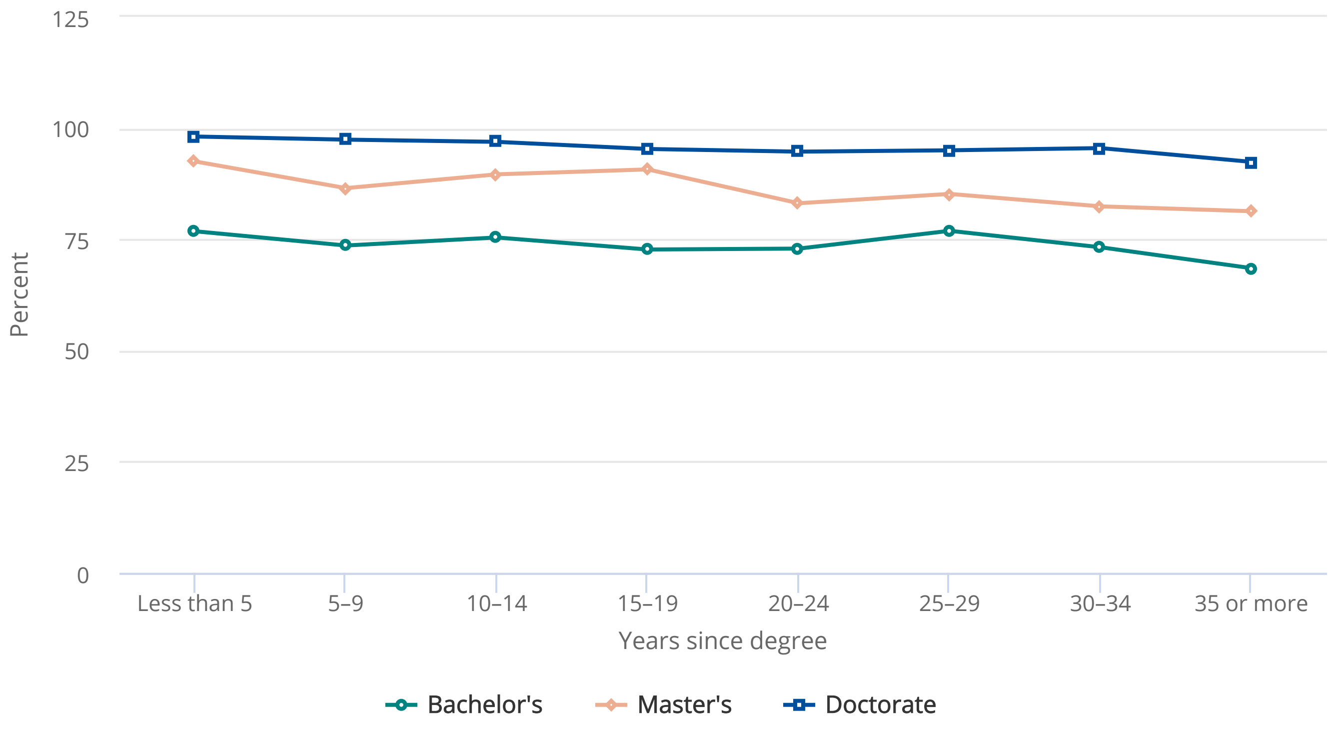
Whereas Figure 3-8 shows the proportion of S&E degree holders employed in S&E occupations, Figure 3-9 shows what proportions of S&E degree holders reported that their work is related (closely or somewhat) to their S&E degree. Workers with more advanced S&E training were more likely than those with only bachelor's degrees to work in a job related to their degree field. Regardless of degree level, most degree holders in life sciences (76%), physical sciences (79%), computer and mathematical sciences (89%), and engineering (90%) considered their jobs to be related to their degree field. The corresponding percentage of social scientists was 68%.

The pattern of a stronger relationship between S&E jobs and S&E degrees among master's degree or doctorate holders compared with bachelor's degree holders is robust across career stages, as seen in comparisons among groups of bachelor's, master's, and doctoral degree holders at comparable numbers of years since receiving their degrees (Figure 3-9). However, at each degree level, the percentage of S&E degree holders employed in jobs related to their field of highest degree declines as the number of years since degree increases. This suggests that the relationship between job and field of highest degree becomes weaker over time, particularly toward the later career stages. Possible reasons for this decline include changes in career interests, development of skills in different areas, promotion to general management positions, or realization that some of the original training has become obsolete. Despite these potential factors, the career-cycle decline in the relevance of an S&E degree appears modest.

FIGURE 3-9

S&E degree holders employed in jobs related to highest degree, by level of and years since highest degree: 2015



Note(s)

Data include those who reported that their job is either closely or somewhat related to the field of their highest degree.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Survey of College Graduates (NSCG) (2015), https://www.nsf.gov/statistics/srvygrads/.

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[1] The standard definition of the term *labor force* is a subset of the population that includes both those who are employed and those who are not working but seeking work (unemployed); other individuals are not considered to be in the labor force. Unless otherwise noted, when data refer only to employed persons, the term *workforce* is used. For data on unemployment rates by occupation, calculations assume that unemployed individuals are seeking further employment in their most recent occupation.

[2] The SOC system is used by federal statistical agencies to classify workers into occupational categories for the purpose of collecting, calculating, and disseminating data. The Current Population Survey currently uses the 2010 Census occupational classification derived from the 2010 Standard Occupational Classification (SOC). The Census classification uses the same basic structure as the SOC but is generally less detailed. Detailed information on the SOC system is available at https://www.bls.gov/SOC/.

[3] As expected, this subjective measure—of the use of technical knowledge, skills, or expertise on the job—varies across occupations. For example, in 2015, among postsecondary teachers of chemistry, almost all those surveyed said that their job required at least a bachelor's degree level of knowledge in engineering, computer sciences, mathematics, or natural sciences. Among postsecondary teachers of business commerce or marketing, 86% said that their job required at least this level of expertise in other fields such as health, business, or education. Among those with at least one degree at the bachelor's level or higher in an S&E or S&E-related field whose occupation is secretary, receptionist, or typist, only about 5% said that their job required a bachelor's degree level of knowledge in engineering, computer sciences, mathematics, or natural sciences; about 9% said that their job required at least a bachelor's degree level of knowledge in social sciences; and 12% said that their job required at least a bachelor's degree level of expertise in other fields such as health, business, or education.

[4] Estimates of the size of the S&E workforce may vary across the different surveys because of differences in the scope of the data collection (the NSCG collects data from individuals with at least a bachelor's degree); because of the type of survey respondent (the NSCG collects data from individuals, the OES survey collects data from employers, and the ACS collects data from households); or because of the level of detail collected on an occupation, which aids in classifying a reported occupation into a standard occupational category. For example, the NSCG estimate of the number of workers in S&E occupations includes postsecondary teachers of S&E fields; however, postsecondary teachers in ACS are grouped under a single occupation code regardless of field and are therefore not included in the ACS estimate of the number of workers in S&E occupations.

[5] Among those with doctorates in an S&E field, life sciences and social sciences were the most common fields, followed by physical sciences, engineering, and computer and mathematical sciences.

[6] The data on S&E employment levels for 1960 and 2015 are calculated using the Census Bureau's 1960 Decennial Census and 2015 ACS microdata, respectively, adjusted by the Integrated Public Use Microdata Series (IPUMS) from the University of Minnesota's Minnesota Population Center (https://www.ipums.org). Occupational classification systems have changed over time, which limits the comparability of occupational counts over time. For example, computer occupations were not present in the occupational classification system used in 1960. For more information on the change in occupational classification systems, see Wyatt and Hecker (2006). S&E employment levels for 1960 and 2015 include workers at all education levels and do not include S&E postsecondary teachers. Although the 1960 Decennial Census data allow for separate identification of S&E postsecondary teachers, the 2015 ACS data aggregate all postsecondary teachers into one occupation code and therefore do not allow for separate identification of S&E postsecondary teachers. For 1960, the inclusion of S&E postsecondary teachers would increase the number of workers employed in S&E occupations to nearly 1.2 million. See Appendix Table 3-1 for a list of S&E occupations in the 1960 Decennial Census and 2015 ACS.

[7] Many comparisons using Census Bureau data on occupations are limited to looking at all S&E occupations except postsecondary teachers because the Census Bureau aggregates all postsecondary teachers into one occupation code. NSF surveys of scientists and engineers and some BLS surveys collect data on postsecondary teachers by field.

S&E Workers in the Economy

To understand the economic and scientific contributions of scientists and engineers, it is important to know how they are distributed across the economy and what kind of work they perform. This section examines the economic sector, size, and other characteristics of organizations that employ scientists and engineers (defined both by occupation and field of education). It also describes the distribution of S&E workers within particular sectors. The analysis covers all sectors: private and public educational institutions; for-profit businesses and nonprofit organizations; and federal, state, and local governments. It also examines self-employed scientists and engineers and the concentration of S&E workers by industry sectors and by geography.

The S&E labor force is a national resource that contributes to productivity increases and innovative capacities required to fuel long-term economic growth and public welfare. The section concludes with examinations of R&D activity and work-related training as indicators of worker skill level, productivity, and innovative capacity. It distinguishes between analyses based on S&E degree field and S&E occupation.

Employment Sectors

The business sector is by far the largest employer of the broad S&E workforce (including those with at least an S&E or S&E-related bachelor's degree and those working in an S&E or S&E-related occupation regardless of having an S&E degree). In 2015, the business sector—mostly for-profit businesses—employed about 71% of such individuals (▦Table 3-6). The education sector, including private and public institutions, employed another 19%, the bulk in 2-year and precollege institutions. The government sector—federal, state, and local—employed another 11%. This distribution pattern has been quite stable for decades, except for a small rise in the nonprofit segment and a small decline in government (Appendix Table 3-4).

Some differences exist in the concentration of particular groups of S&E workers across employment sectors. For example, academic institutions are the largest employer of scientists and engineers with doctorates, although the business sector is the largest employer of scientists and engineers overall. Whereas individuals employed in engineering occupations and computer and mathematical sciences occupations are largely concentrated in the business sector, those employed as life scientists, physical scientists, and social scientists are more evenly distributed between the business sector and education and government sectors together. The following discussion provides a deeper analysis of the economic sectors in which scientists and engineers work.

TABLE 3-6

Employment sector of scientists and engineers, by broad occupational category and degree field: 2015

(Percent)

Employment sector	All employed scientists and engineers	Highest degree in S&E	S&E occupations	S&E-related occupations	Non-S&E occupations
Total (number)	25,306,000	13,497,000	6,407,000	7,867,000	11,031,000
Business or industry	70.7	72.3	71.5	69.9	70.8
For-profit businesses	53.7	58.9	63.6	47.7	52.4
Nonprofit organizations	10.8	7.3	4.7	17.9	9.3
Self-employed, unincorporated businesses	6.2	6.1	3.2	4.3	9.3
Education	18.5	15.8	17.2	21.8	16.9
4-year institutions	7.8	8.8	14.2	6.2	5.3
2-year and precollege institutions	10.7	7.1	3.0	15.6	11.6
Government	10.8	11.9	11.3	8.4	12.2
Federal	4.6	5.3	5.8	3.7	4.5
State or local	6.2	6.5	5.5	4.7	7.7

Note(s)

Scientists and engineers include those with one or more S&E or S&E-related degrees at the bachelor's level or higher or those who have only a non-S&E degree at the bachelor's level or higher and are employed in an S&E or S&E-related occupation. Detail may not add to total because of rounding.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Survey of College Graduates (NSCG) (2015), https://www.nsf.gov/statistics/srvygrads/.

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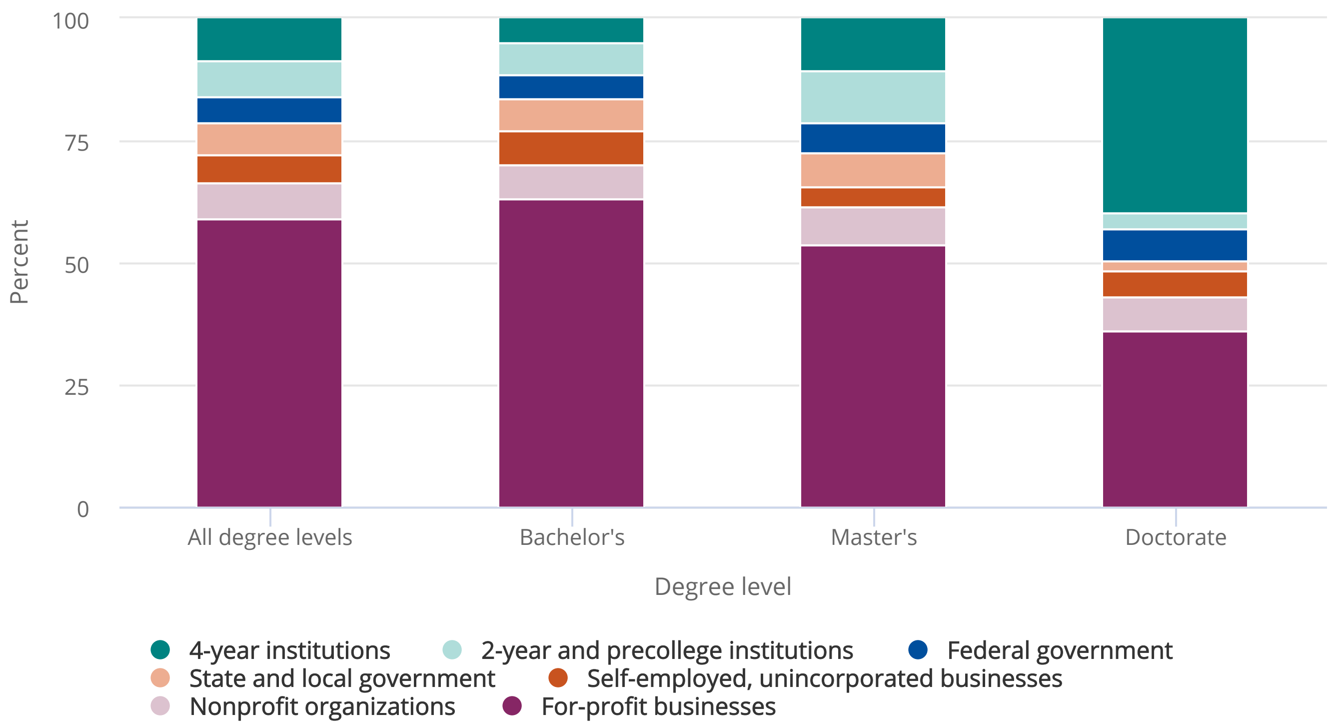
Education Sector

The education sector employs nearly one-fifth of the S&E workforce but is segmented by level of S&E education (Table 3-6; Figure 3-10; Appendix Table 3-5). The vast majority of S&E doctorate holders in this sector work in 4-year institutions as faculty, postdoctorates (postdocs), research staff, and a variety of other full- and part-time positions. The majority of bachelor's level scientists and engineers work in 2-year and precollege institutions. (See Chapter 5 for additional detail on academic employment of science, engineering, and health [SEH] doctorate holders.)

The subsectoral employment distribution also differs for those in S&E occupations. Larger proportions of life, physical, and social scientists work in the education sector, compared with engineers or computer and mathematical scientists (Figure 3-11). Within the education sector, the vast majority (82%) of those in S&E occupations are concentrated in 4-year institutions. In contrast, the great majority of workers in S&E-related or non-S&E occupations in the education sector are found in 2-year and precollege institutions (71% and 69%, respectively), and the bulk of them are employed as teachers.

FIGURE 3-10

S&E highest degree holders, by degree level and employment sector: 2015



Note(s)

All degree levels includes professional degrees not shown separately.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Survey of College Graduates (NSCG) (2015), https://www.nsf.gov/statistics/srvygrads/.

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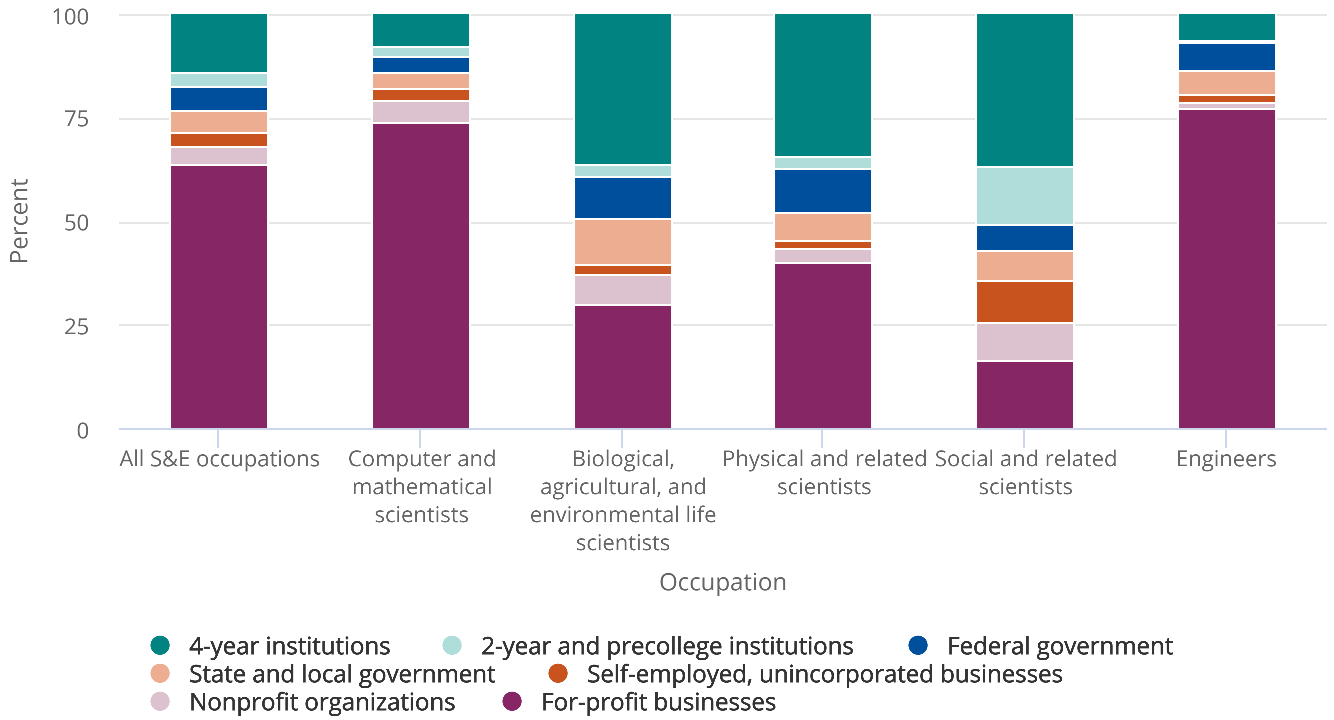
FIGURE 3-11

Broad S&E occupational categories, by employment sector: 2015



Note(s)

Percentages may not add to 100% because of rounding.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Survey of College Graduates (NSCG) (2015), https://www.nsf.gov/statistics/srvygrads/.

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Business Sector

For-profit businesses. For-profit businesses employ the largest proportion of scientists and engineers (Table 3-6). At the doctorate level, however, the proportions employed by for-profit businesses (36%) and 4-year educational institutions (40%) are similar (Figure 3-10; Appendix Table 3-5; also, see sidebar Patterns of Mobility of New S&E PhDs into the Business Sector). Employment also varies by occupational categories. The majority of those working in computer and mathematical sciences occupations (74%) and in engineering occupations (77%) are employed by for-profit businesses, but the proportions are much lower for those in other S&E occupations, ranging from 16% for social scientists to 40% for physical scientists (Figure 3-11).

Nonprofit organizations. Employment of scientists and engineers in nonprofit businesses has grown (Appendix Table 3-4), with particularly strong growth among S&E-related occupations, which include health-related jobs. Continuing the trend seen in the broader economy, the number of health-related jobs in nonprofit organizations has risen dramatically from 97,000 in 1993 to 1.2 million in 2015. As a result, the total share of all health-related occupations in nonprofit organizations has risen from 13% in 1993 to 25% in 2015. Nearly half (47%) of such workers are employed as registered nurses, dieticians, therapists, physician assistants, and nurse practitioners.

Among those in S&E occupations, the proportion employed by nonprofit organizations is much smaller (5%) (Table 3-6), with substantial variation among different fields, ranging from 2% of engineers to 10% of social scientists and 7% of life scientists (Figure 3-11).

Self-employment. In 2015, almost 4.3 million scientists and engineers (17%) reported being self-employed in either an unincorporated or incorporated business, professional practice, or farm (Table 3-7).[1] Those working in S&E-related or non-S&E occupations reported higher levels of self-employment (15% and 22%, respectively) than those working in S&E occupations (11%). Among those with a highest degree in S&E, individuals with professional degrees reported substantially higher rates of self-employment (35%) than those with a bachelor's degree (17%), master's degree (12%), or doctorate (12%) as their highest degree.

Incorporated businesses account for at least half of self-employed scientists and engineers in most fields (Table 3-7). However, most of those in social science occupations worked in unincorporated businesses, which was largely driven by psychologists. In 2015, among the 213,000 employed psychologists, 28% were self-employed, mostly in unincorporated businesses. In addition, 39% of professional degree holders in a field of psychology were self-employed, also with most employed in unincorporated businesses.

TABLE 3-7

Self-employed scientists and engineers, by education, occupation, and type of business: 2015

(Percent)

Characteristic	Total	Unincorporated business	Incorporated business
All employed scientists and engineers	16.8	6.2	10.7
Highest degree in S&E field	16.6	6.1	10.4
Biological, agricultural, and environmental life sciences	16.4	6.7	9.7
Computer and mathematical sciences	13.3	3.6	9.6
Physical sciences	11.2	4.3	6.7
Social sciences	19.0	8.6	10.4
Engineering	16.6	4.2	12.4
S&E highest degree level			
Bachelor's	17.0	6.3	10.7
Master's	12.3	4.3	8.1
Doctorate	11.6	5.1	6.4
Professional	34.5	12.5	22.0
Occupation			
S&E occupation	10.6	3.2	7.5
Biological, agricultural, and environmental life scientists	5.1	2.1	3.0
Computer and mathematical scientists	11.4	2.9	8.5
Physical scientists	6.0	2.1	3.9
Social scientists	14.0	9.8	4.0
Engineers	11.1	2.0	9.0
S&E-related occupations	15.1	4.3	10.8
Non-S&E occupations	21.6	9.3	12.4

Note(s)

Scientists and engineers include those with one or more S&E or S&E-related degrees at the bachelor's level or higher or those who have only a non-S&E degree at the bachelor's level or higher and are employed in an S&E or S&E-related occupation. Detail may not add to total because of rounding.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Survey of College Graduates (NSCG) (2015), https://www.nsf.gov/statistics/srvygrads/.

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Government Sector

Federal government. According to data from the U.S. Office of Personnel Management (OPM), the federal government employed approximately 329,000 people in S&E occupations in 2016, which represents about 16% of the federal civilian workforce.[2] ,[3] Federal workers in S&E occupations are almost evenly distributed among computer and mathematical sciences occupations (33%); engineering occupations (31%); and life sciences, physical sciences, and social sciences occupations (36%). The majority (81%) of the federal workers in S&E occupations have a bachelor's or higher level degree.

The five federal agencies with the largest proportions of their workforce in S&E jobs are those with strong scientific missions: the National Aeronautics and Space Administration (66%), the Nuclear Regulatory Commission (63%), the Environmental Protection Agency (61%), NSF (41%), and the Department of Energy (33%). The Department of Defense has the largest number of workers in S&E occupations (154,000), accounting for 47% of the federal workforce in S&E occupations.[4]

State and local government. In 2015, about 1.6 million scientists and engineers (6%) were working in state and local governments in the United States (▦ Table 3-6). Public educational institutions are included in the education sector and excluded here. State and local governments employ about 7% of both S&E bachelor's degree holders and S&E master's degree holders, compared to only 2% of S&E doctorate holders (📊 Figure 3-10). Among those employed in S&E occupations, larger proportions of life scientists, physical scientists, and social scientists work in state and local governments, compared with computer and math scientists (📊 Figure 3-11).

SIDEBAR

Patterns of Mobility of New S&E PhDs into the Business Sector

About half of the 500,000 new S&E doctorate recipients during the 2001–15 period reported postgraduation plans for employment, and of those, a quarter were going into the business sector. Data from the Survey of Earned Doctorates (SED) can track the geographic mobility of newly minted S&E PhDs from training to industry employment, which not only informs the understanding of geographic patterns of R&D activity but is also an important indicator of local knowledge spillovers from academia to the business sector (Stephan 2007). Firms hire new S&E PhDs for their ability to contribute to R&D and other innovative activities within the organization. Where they are placed is an important indicator of regional innovative capacity. In addition, the resulting knowledge flows from academia to industry via employment of new S&E doctorate holders are related to the innovative capacity of a region. Following Stephan (2007), SED data from 2001–15 were examined to analyze the geographic mobility of new PhDs with postgraduation plans for business-sector employment in the United States.

From 2001 to 2015, nearly 57,000 new doctorate recipients in S&E fields had postgraduation plans for non-postdoc employment in industry in the United States (Table 3-B). The rate at which these newly graduated students entered into business-sector employment in the region in which they trained is an indicator of local knowledge spillover effects from academia to the business sector. These rates vary substantially by region, ranging from a high of 77% remaining in the Pacific and Insular region, which includes the Pacific states and Puerto Rico and outlying territories (see Table 3-C for a list of states and territories included in each region), to nearly one-third (32%) in the East South Central United States. States vary considerably in terms of economic and employment opportunities. The Pacific and Insular region attracted the most S&E PhDs overall for business-sector employment (17,332), regardless of where training occurred, followed by the Middle Atlantic region (9,601). In comparison, the East South Central region attracted the lowest number of S&E PhDs to work in industry (951) during this time period.

TABLE 3-B

Doctorate recipients in S&E fields with postgraduation plans for non-postdoc employment in the United States in the business or industry sector, by region of doctoral institution and region of employment: 2001–15 combined

(Number and percent distribution)

Region of employment	Region of doctoral institution									
	New England	Middle Atlantic	East North Central	West North Central	South Atlantic	East South Central	West South Central	Mountain	Pacific and Insular	All doctoral institutions
Number										
All employment[a]	4,566	9,106	10,212	3,756	9,325	1,652	5,110	2,979	10,119	56,825
New England	2,212	722	545	176	495	71	150	98	293	4,762
Middle Atlantic	786	4,700	1,256	368	1,084	150	297	178	782	9,601
East North Central	176	411	3,867	454	566	190	244	96	245	6,249
West North Central	59	112	386	1,342	180	60	109	58	97	2,403
South Atlantic	262	640	675	287	4,149	229	268	125	311	6,946
East South Central	19	45	89	54	116	525	62	19	22	951
West South Central	162	329	574	248	595	136	2,910	249	311	5,514
Mountain	75	202	285	143	253	53	142	1,438	225	2,816
Pacific and Insular	786	1,900	2,491	666	1,839	233	906	706	7,805	17,332
Percent distribution of region of doctoral institution across regions of employment										
All employment[b]	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Region of employment	Region of doctoral institution									
	New England	Middle Atlantic	East North Central	West North Central	South Atlantic	East South Central	West South Central	Mountain	Pacific and Insular	All doctoral institutions
New England	48.4	7.9	5.3	4.7	5.3	4.3	2.9	3.3	2.9	8.4
Middle Atlantic	17.2	51.6	12.3	9.8	11.6	9.1	5.8	6.0	7.7	16.9
East North Central	3.9	4.5	37.9	12.1	6.1	11.5	4.8	3.2	2.4	11.0
West North Central	1.3	1.2	3.8	35.7	1.9	3.6	2.1	1.9	1.0	4.2
South Atlantic	5.7	7.0	6.6	7.6	44.5	13.9	5.2	4.2	3.1	12.2
East South Central	0.4	0.5	0.9	1.4	1.2	31.8	1.2	0.6	0.2	1.7
West South Central	3.5	3.6	5.6	6.6	6.4	8.2	56.9	8.4	3.1	9.7
Mountain	1.6	2.2	2.8	3.8	2.7	3.2	2.8	48.3	2.2	5.0
Pacific and Insular	17.2	20.9	24.4	17.7	19.7	14.1	17.7	23.7	77.1	30.5

[a] Total employment counts include doctorate recipients reporting unknown U.S. location.

[b] Employment percentages do not sum to 100% because total counts include doctorate recipients reporting unknown U.S. location.

Note(s)

Numbers are based on doctorate recipients reporting definite commitments for non-postdoc employment in the year after doctoral degree award. S&E fields include life sciences, physical and earth sciences, mathematics and computer sciences, psychology and social sciences, and engineering. Business or industry sector includes self-employment and excludes not-for-profit organizations.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2017), Survey of Earned Doctorates (SED) (2015).

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TABLE 3-C

Region and state of doctoral institution and employment of doctorate recipients in S&E fields with postgraduation plans for non-postdoc employment in the United States in the business or industry sector: 2001–15 combined

(Number)

Region and state	PhDs trained in state or region	New PhDs working in state or region	Number of new PhDs produced that stay in state or region	Percent of new PhDs produced that stay in state or region
New England	4,566	4,762	2,212	48.4
Connecticut	669	859	171	25.6
Maine	40	57	16	40.0
Massachusetts	3,379	3,401	1,556	46.0
New Hampshire	159	195	32	20.1
Rhode Island	279	126	56	20.1
Vermont	40	124	19	47.5
Middle Atlantic	9,106	9,601	4,700	51.6
New Jersey	1,561	2,700	690	44.2
New York	4,273	4,741	1,744	40.8
Pennsylvania	3,272	2,160	879	26.9
East North Central	10,212	6,249	3,867	37.9
Illinois	3,291	2,149	929	28.2
Indiana	1,641	780	225	13.7
Michigan	2,100	1,502	701	33.4
Ohio	1,913	1,165	613	32.0
Wisconsin	1,267	653	290	22.9
West North Central	3,756	2,403	1,342	35.7
Iowa	761	274	142	18.7
Kansas	451	253	128	28.4
Minnesota	1,311	1,124	467	35.6
Missouri	820	527	236	28.8

Region and state	PhDs trained in state or region	New PhDs working in state or region	Number of new PhDs produced that stay in state or region	Percent of new PhDs produced that stay in state or region
Nebraska	242	134	77	31.8
North Dakota	109	55	32	29.4
South Dakota	62	36	18	29.0
South Atlantic	9,325	6,946	4,149	44.5
Delaware	395	320	61	15.4
District of Columbia	369	521	61	16.5
Florida	1,717	1,062	647	37.7
Georgia	1,772	806	427	24.1
Maryland	1,258	1,175	402	32.0
North Carolina	1,699	1,236	627	36.9
South Carolina	445	317	125	28.1
Virginia	1,505	1,415	526	35.0
West Virginia	165	94	39	23.6
East South Central	1,652	951	525	31.8
Alabama	483	292	143	29.6
Kentucky	340	179	91	26.8
Mississippi	233	87	45	19.3
Tennessee	596	393	178	29.9
West South Central	5,110	5,514	2,910	56.9
Arkansas	144	128	65	45.1
Louisiana	414	250	110	26.6
Oklahoma	379	261	108	28.5
Texas	4,173	4,875	2,348	56.3
Mountain	2,979	2,816	1,438	48.3
Arizona	961	1,010	360	37.5

Region and state	PhDs trained in state or region	New PhDs working in state or region	Number of new PhDs produced that stay in state or region	Percent of new PhDs produced that stay in state or region
Colorado	918	891	473	51.5
Idaho	99	205	44	44.4
Montana	59	36	20	33.9
Nevada	139	114	68	48.9
New Mexico	189	213	74	39.2
Utah	549	310	206	37.5
Wyoming	65	37	20	30.8
Pacific and Insular	10,119	17,332	7,805	77.1
Alaska	18	39	7	38.9
California	8,690	13,150	6,180	71.1
Hawaii	71	86	42	59.2
Oregon	416	2,088	207	49.8
Washington	847	1,878	401	47.3
Puerto Rico and outlying territories	77	91	66	85.7

Note(s)

Numbers and percentages are based on doctorate recipients reporting definite commitments for non-postdoc employment in the year after doctoral degree award, with response to location of employment. S&E fields include life sciences, physical and earth sciences, mathematics and computer sciences, psychology and social sciences, and engineering. Business or industry sector includes self-employment and excludes not-for-profit organizations.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2017), Survey of Earned Doctorates (SED) (2015).

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As S&E doctorate recipients become increasingly geographically concentrated by region of planned employment in the business sector, the share of where they are trained by region has remained fairly stable since 2001. ▦ Table 3-D and ▦ Table 3-E show the number and share of new S&E doctorate holders with postgraduation plans for employment in business or industry by region of doctoral institution and by location of employment, respectively, for three 5-year cohorts. While the Pacific and Insular region accounts for just under 20% of the training of the three graduating cohorts, between 27% and 34% of these cohorts are planning to work in the business sector in this region. This suggests that this region increasingly accounts for a larger share of new S&E PhD workers in the business sector, while the share trained there remains stable over this time period. The Middle Atlantic region has declined in its share of business-sector employment plans of these new graduates, down from 19% in the first cohort to 15% in the most recent cohort. The South Atlantic region saw a slight decline in its share of those planning to be employed in the business sector there, while the West South Central region saw a modest increase.

TABLE 3-D

Doctorate recipients in S&E fields with postgraduation plans for non-postdoc employment in the United States in the business or industry sector, by region of doctoral institution: 5-year cohorts, 2001–15

(Number and percent)

Region	2001–05	2006–10	2011–15
Number			
All regions	16,328	19,584	20,913
New England	1,298	1,576	1,692
Middle Atlantic	2,673	3,159	3,274
East North Central	3,034	3,449	3,729
West North Central	1,111	1,287	1,358
South Atlantic	2,564	3,191	3,570
East South Central	453	574	625
West South Central	1,395	1,699	2,016
Mountain	850	1,040	1,089
Pacific and Insular	2,950	3,609	3,560
Percent			
All regions	100.0	100.0	100.0
New England	7.9	8.0	8.1
Middle Atlantic	16.4	16.1	15.7
East North Central	18.6	17.6	17.8
West North Central	6.8	6.6	6.5
South Atlantic	15.7	16.3	17.1
East South Central	2.8	2.9	3.0
West South Central	8.5	8.7	9.6
Mountain	5.2	5.3	5.2
Pacific and Insular	18.1	18.4	17.0

Note(s)

Numbers and percentages are based on doctorate recipients reporting definite commitments for non-postdoc employment in the year after doctoral degree award, with response to location of employment. S&E fields include life sciences, physical and earth sciences, mathematics and computer sciences, psychology and social sciences, and engineering. Business or industry sector includes self-employment and excludes not-for-profit organizations.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2017), Survey of Earned Doctorates (SED) (2015).

Science and Engineering Indicators 2018

TABLE 3-E

Doctorate recipients in S&E fields with postgraduation plans for non-postdoc employment in the United States in the business or industry sector, by region of employment: 5-year cohorts, 2001–15

(Number and percent)

Region	2001–05	2006–10	2011–15
Number			
All regions[a]	16,328	19,584	20,913
New England	1,438	1,592	1,732
Middle Atlantic	3,132	3,325	3,144
East North Central	1,909	2,099	2,241
West North Central	703	790	910
South Atlantic	2,145	2,428	2,373
East South Central	269	333	349
West South Central	1,417	1,984	2,113
Mountain	858	1,002	956
Pacific and Insular	4,391	5,904	7,037
Percent			
All regions[b]	100.0	100.0	100.0
New England	8.8	8.1	8.3
Middle Atlantic	19.2	17.0	15.0
East North Central	11.7	10.7	10.7
West North Central	4.3	4.0	4.4
South Atlantic	13.1	12.4	11.3
East South Central	1.6	1.7	1.7
West South Central	8.7	10.1	10.1
Mountain	5.3	5.1	4.6
Pacific and Insular	26.9	30.1	33.6

[a] Totals include doctorate recipients with unknown region of U.S. employment.

[b] Percentages do not sum to 100% because total counts include doctorate recipients with unknown region of U.S. employment.

Note(s)

Numbers and percentages are based on doctorate recipients reporting definite commitments for non-postdoc employment in the year after doctoral degree award, with response to location of employment. S&E fields include life sciences, physical and earth sciences, mathematics and computer sciences, psychology and social sciences, and engineering. Business or industry sector includes self-employment and excludes not-for-profit organizations.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2017), Survey of Earned Doctorates (SED) (2015).

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The flow of new S&E PhDs with postgraduation plans for business-sector employment outside of the region in which they trained increased slightly from the turn of the century until 2015 (▦ Table 3-F). The rate at which these students plan to remain in their region of training for postgraduation industry employment has declined overall from 53% in the earliest cohort to 49% in the most recent cohort. The only region that saw an increase in the rate at which new S&E PhDs remain for business-sector employment was the Pacific and Insular region, where the proportion rose slightly from 76% in both the 2001–05 and 2006–10 cohorts, respectively, to 79% in the most recent cohort overall. This proportion declined in the South Atlantic region from 49% in 2001–05 to 41% in 2011–15 and also in the Middle Atlantic region from 56% to 48%. ▦ Table 3-C breaks down these proportions by state for the entire period of 2001–15, showing that in the Pacific and Insular region, California accounts for the largest share of new S&E PhDs trained and employed there. Within this region, California has one of the highest rates at which those trained in that state also remain there for business-sector employment.

TABLE 3-F

Doctorate recipients in S&E fields with postgraduation plans for non-postdoc employment in the United States in the business or industry sector, by region of doctoral institution: 5-year cohorts, 2001–15

(Number and percent)

Region	2001–05	2006–10	2011–15
Number of new doctorates trained in region			
All regions	16,328	19,584	20,913
New England	1,298	1,576	1,692
Middle Atlantic	2,673	3,159	3,274
East North Central	3,034	3,449	3,729
West North Central	1,111	1,287	1,358
South Atlantic	2,564	3,191	3,570
East South Central	453	574	625
West South Central	1,395	1,699	2,016
Mountain	850	1,040	1,089
Pacific and Insular	2,950	3,609	3,560
Number of new doctorates produced that stay in region			
All regions[a]	8,703	9,933	10,340
New England	639	744	829
Middle Atlantic	1,501	1,635	1,564
East North Central	1,246	1,273	1,348
West North Central	416	429	497
South Atlantic	1,246	1,442	1,461
East South Central	160	173	192
West South Central	790	995	1,125
Mountain	449	485	504
Pacific and Insular	2,245	2,743	2,817
Percent of new doctorates produced that stay in region			

Region	2001–05	2006–10	2011–15
All regions	53.3	50.7	49.4
New England	49.2	47.2	49.0
Middle Atlantic	56.2	51.8	47.8
East North Central	41.1	36.9	36.1
West North Central	37.4	33.3	36.6
South Atlantic	48.6	45.2	40.9
East South Central	35.3	30.1	30.7
West South Central	56.6	58.6	55.8
Mountain	52.8	46.6	46.3
Pacific and Insular	76.1	76.0	79.1

[a] Totals include doctorate recipients with unknown region of U.S. employment.

Note(s)

Numbers and percentages are based on doctorate recipients reporting definite commitments for non-postdoc employment in the year after doctoral degree award, with response to location of employment. S&E fields include life sciences, physical and earth sciences, mathematics and computer sciences, psychology and social sciences, and engineering. Business or industry sector includes self-employment and excludes not-for-profit organizations.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2017), Survey of Earned Doctorates (SED) (2015).

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Overall, while the geographic distribution of S&E PhDs by educational institution has remained stable among all nine U.S. regions since 2001, the plans for industry employment of these new graduates has shifted toward the Pacific Coast—primarily California. The Middle Atlantic and South Atlantic regions seem to be the hardest hit by the shift, having the largest drops in the percentage of S&E doctorate holders who plan to remain and work in industries located in those regions after graduation. There is wide variation in the geographic distribution of S&E PhDs by both region of training and region of employment. Of the nearly 57,000 new S&E PhDs planning to work in the business sector, most are in the Pacific and Insular region, and the East South Central region has the fewest training and planning to work in industry in that area.

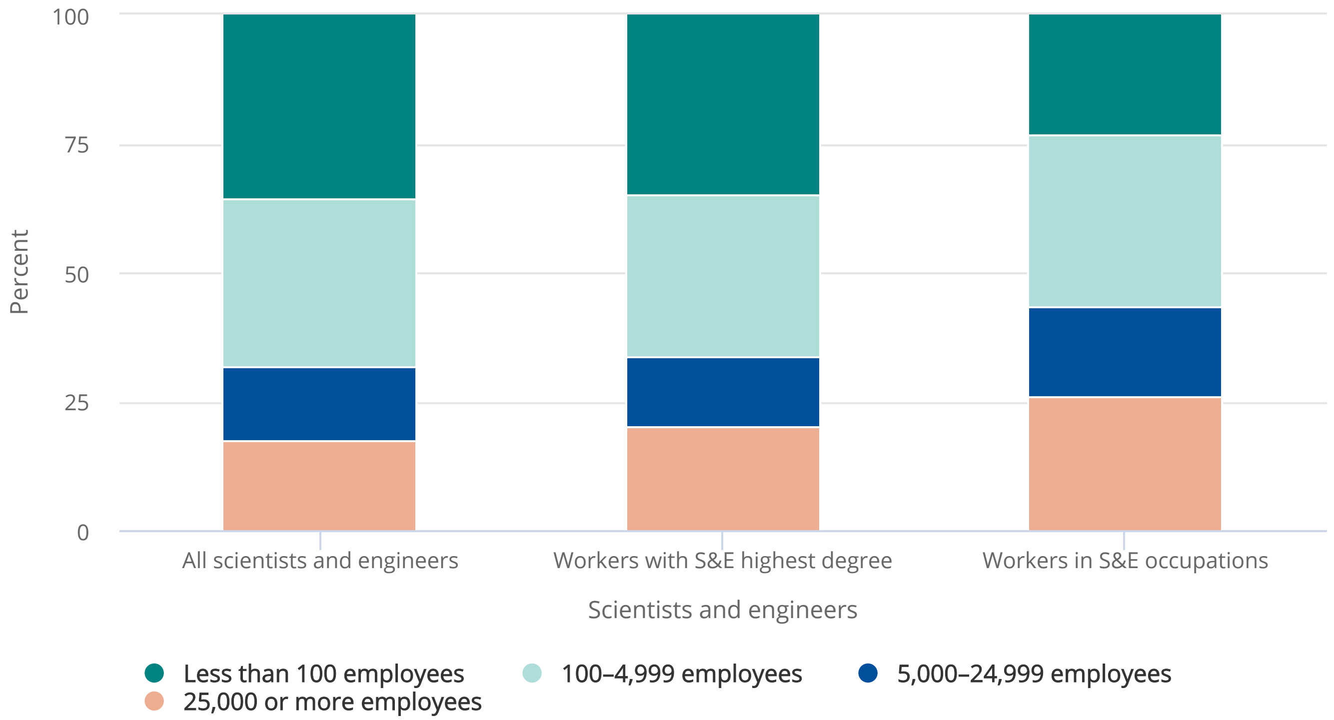
Employer Size

The majority of educational institutions and government entities that employ individuals trained in S&E fields or working in S&E occupations are large employers (i.e., having 100 or more employees). These large organizations employ 87% of scientists and engineers in the education sector and 92% of those in the government sector. In contrast, scientists and engineers working in the business sector are more broadly distributed across firms of different sizes (📊 Figure 3-12).

Many scientists and engineers who are self-employed work in businesses with 10 or fewer employees. In all, 84% of self-employed individuals in unincorporated businesses and 45% of self-employed individuals in incorporated businesses work in businesses with 10 or fewer employees. In contrast, only 5% of all other scientists and engineers work in businesses with 10 or fewer employees. Many of these scientists and engineers likely think of themselves as independent professionals rather than small-business owners.

FIGURE 3-12

Scientists and engineers employed in the business sector, by employer size: 2015



Note(s)

Scientists and engineers include those with one or more S&E or S&E-related degrees at the bachelor's level or higher or those who have only a non-S&E degree at the bachelor's level or higher and are employed in an S&E or S&E-related occupation. Percentages may not add to 100% because of rounding.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Survey of College Graduates (NSCG) (2015), https://www.nsf.gov/statistics/srvygrads/.

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Industry Employment

The OES survey provides detailed estimates for employment in S&E occupations by type of industry; however, it excludes self-employed individuals, those employed in private households, and some individuals employed in agriculture. Industries vary in their proportions of S&E workers (Table 3-8). In 2016, the industry group with the largest S&E employment was professional, scientific, and technical services (2.1 million),[5] followed by manufacturing (937,000) (Table 3-8). The government sector, which includes federal, state, and local governments, employed 652,000 S&E workers; educational services, including private and public educational institutions, employed another 702,000 S&E workers. These four industry groups—professional, scientific, and technical services; manufacturing; government; and educational services—had a disproportionate concentration of S&E workers and together accounted for about 66% of S&E employment, compared with 31% of total employment.

S&E employment intensity, defined by an industry's S&E employment as a proportion of its total employment, was highest in professional, scientific, and technical services (24%), followed by information (20%) and by management of companies and enterprises (14%) (Table 3-8). The broad industry sectors with S&E employment intensity below the national average (4.8%) together employed 60% of all workers in 2016 but only 14% of workers in S&E occupations. These sectors with S&E employment intensity below the national average include large employers such as health care and social assistance, retail trade, and accommodation and food services. The health care and social assistance industry employed a large number of health workers who fall under NSF's category of S&E-related occupations (Table 3-2).

TABLE 3-8

Employment in S&E occupations, by major industry: May 2016

(Number)

Industry	Workers employed		Industry workforce in S&E occupations (%)
	All occupations	S&E occupations	
U.S. total — all industries	140,400,040	6,746,600	4.8
Agriculture, forestry, fishing, and hunting	416,600	1,660	0.4
Mining	649,130	50,140	7.7
Utilities	549,960	60,770	11.0
Construction	6,687,380	66,570	1.0
Manufacturing	12,337,520	937,150	7.6
Wholesale trade	5,840,730	246,330	4.2
Retail trade	15,982,520	50,140	0.3
Transportation and warehousing	5,606,180	44,880	0.8
Information	2,762,090	563,200	20.4
Finance and insurance	5,775,240	355,630	6.2
Real estate, rental, and leasing	2,110,600	17,180	0.8
Professional, scientific, and technical services	8,739,110	2,136,370	24.4
Management of companies and enterprises	2,302,590	312,650	13.6
Administrative and support and waste management and remediation	9,070,140	266,330	2.9
Educational services	12,982,910	701,850	5.4
Health care and social assistance	19,257,910	217,230	1.1
Arts, entertainment, and recreation	2,322,400	12,190	0.5
Accommodation and food services	13,338,870	4,390	0.0
Other services (except federal, state, and local government)	4,078,800	49,640	1.2
Federal, state, and local government (OES designation)	9,589,350	652,280	6.8

OES = Occupational Employment Statistics.

Note(s)

Industries are defined by the North American Industry Classification System (NAICS). The OES survey does not cover employment among self-employed workers and employment in private households (NAICS 814). In the employment total for agriculture, forestry, fishing, and hunting, only the following industries are included: logging (NAICS 1133), support activities for crop production (NAICS 1151), and support activities for animal production (NAICS 1152). As a result, the data do not represent total U.S. employment. Differences between any two industry groups may not be statistically significant. Detail may not add to total because of rounding.

Source(s)

Bureau of Labor Statistics, special tabulations (2017) of May 2016 OES Survey.

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Employment by Metropolitan Area

The availability of a skilled workforce is an important indicator of a region's population, productivity, and technological growth (Carlino, Chatterjee, and Hunt 2001; Glaeser and Saiz 2003). The federal government uses standard definitions to describe geographical regions in the United States for comparative purposes. It designates very large metropolitan areas, sometimes dividing them into smaller metropolitan divisions that can also be substantial in size (OMB 2009).

This section presents the following indicators of the availability of S&E workers in a metropolitan area: (1) the number of S&E workers in the metropolitan area or division, and (2) the proportion of the entire metropolitan area workforce in S&E occupations. Data on the metropolitan areas with the largest proportion of workers in S&E occupations in 2016 appear in ▦Table 3-9. These estimates are affected by the geographic scope of each metropolitan area, which can vary significantly. In particular, comparisons between areas can be strongly affected by how much territory outside the urban core is included in the metropolitan area.

S&E employment in the United States is geographically concentrated; that is, a small number of geographic areas account for a significant proportion of S&E jobs. For example, the 20 metropolitan areas listed in ▦Table 3-9 account for 19% of nationwide employment in S&E jobs, compared to about 9% of employment in all occupations.

TABLE 3-9

Metropolitan areas with largest proportion of workers in S&E occupations: May 2016

(Number)

Metropolitan area	Workers employed		Metropolitan area workforce in S&E occupations (%)
	All occupations	S&E occupations	
U.S. total	140,400,040	6,746,600	4.8
California-Lexington Park, MD	44,000	8,250	18.8
San Jose-Sunnyvale-Santa Clara, CA	1,045,430	179,820	17.2
Boulder, CO	176,230	25,780	14.6
Framingham, MA NECTA Division	174,430	22,680	13.0
Huntsville, AL	218,260	28,250	12.9
San Francisco-Redwood City-South San Francisco, CA Metropolitan Division	1,067,130	117,500	11.0
Washington-Arlington-Alexandria, DC-VA-MD-WV Metropolitan Division	2,490,690	267,000	10.7
Seattle-Bellevue-Everett, WA Metropolitan Division	1,588,590	169,210	10.7
Durham-Chapel Hill, NC	292,800	30,620	10.5
Lowell-Billerica-Chelmsford, MA-NH NECTA Division	151,310	15,730	10.4
Silver Spring-Frederick-Rockville, MD Metropolitan Division	581,380	58,830	10.1
Corvallis, OR	32,930	3,270	9.9
Ann Arbor, MI	210,990	19,100	9.1
Trenton, NJ	225,950	20,180	8.9
Madison, WI	381,890	34,080	8.9
Raleigh, NC	595,370	52,690	8.8
Boston-Cambridge-Newton, MA NECTA Division	1,803,030	159,430	8.8
Ames, IA	43,690	3,850	8.8
Ithaca, NY	50,590	4,450	8.8
Austin-Round Rock, TX	965,100	81,190	8.4

NECTA = New England City and Town Area.

Note(s)

The data exclude metropolitan statistical areas where S&E proportions were suppressed. Larger metropolitan areas are broken into component metropolitan divisions. Differences between any two areas may not be statistically significant.

Source(s)

Bureau of Labor Statistics, Occupational Employment Statistics (OES) survey (May 2016).

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Scientists and Engineers and Innovation-Related Activities

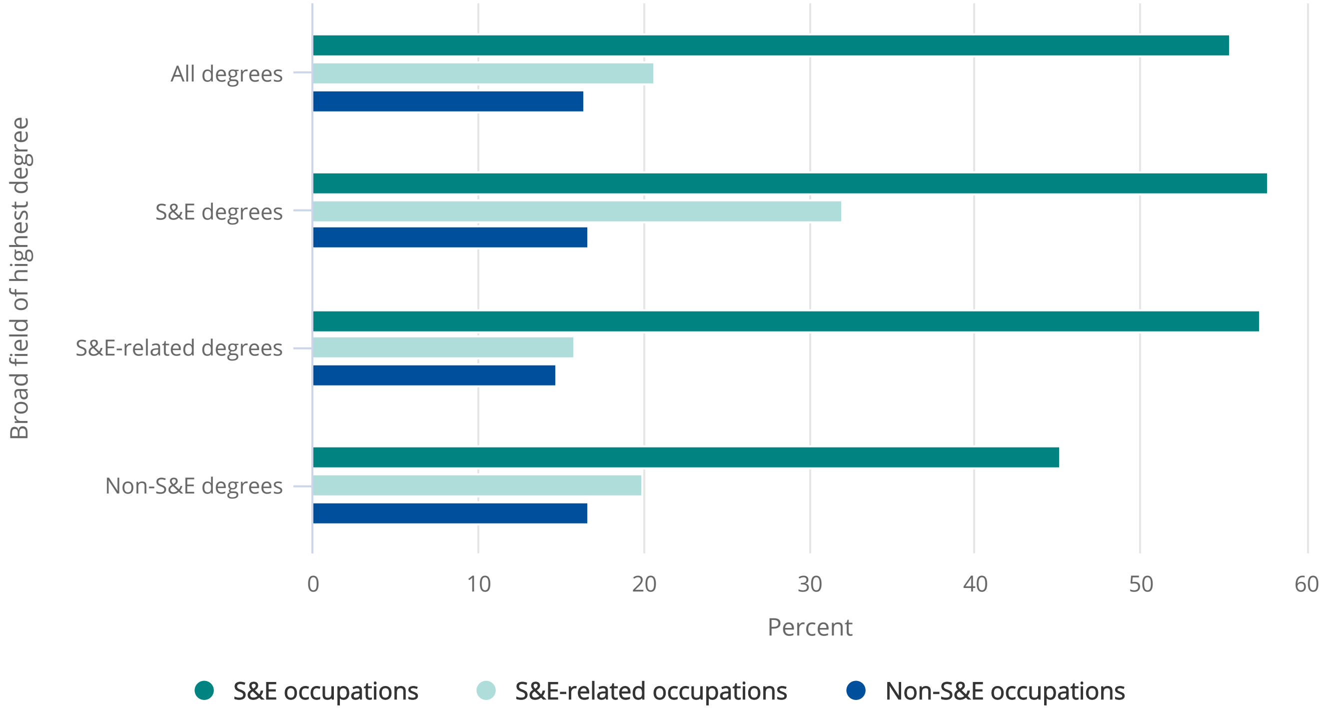
Who Performs R&D?

R&D creates new types of goods and services that can contribute to economic and productivity growth and enhance living standards. Thus, the status of the nation's R&D workforce is a policy area of concern nationally, regionally, and, increasingly, locally. This section uses NSF's NSCG data to examine the R&D activity of scientists and engineers. In this section, the R&D workforce is defined as the proportion of workers who reported basic research, applied research, design, or development as a primary or secondary work activity in their principal job (i.e., activities that rank first or second in total work hours from a list of 14 activities).[6]

Overall, 28% of employed scientists and engineers in 2015 reported R&D as a primary or secondary work activity; the proportions who did so vary substantially across occupations and degrees (Figure 3-13). The majority of individuals in S&E occupations (55%) reported performing R&D, but so did a considerable proportion of those in S&E-related occupations (21%) and non-S&E occupations (16%). This indicates that, although R&D activity spans a broad range of occupations, it is concentrated in S&E occupations. Among those with a non-S&E highest degree but working in an S&E occupation, a sizeable proportion reported R&D activity (45%), although this proportion is lower than for their colleagues with a highest degree in an S&E field (58%). A sizeable proportion of those with S&E degrees do not perform R&D—among them, many S&E degree holders subsequently earn degrees in fields such as medicine, law, or business. In 2015, the majority of S&E bachelor's degree holders who subsequently obtained an advanced degree (60%) earned it in an S&E-related field (18%) or non-S&E field (42%). Additionally, among S&E bachelor's degree holders who reported a second major for their bachelor's degree, about 59% designated an S&E-related field (4%) or non-S&E field (55%) as their second major.

FIGURE 3-13

Employed scientists and engineers with R&D activity, by broad field of highest degree and broad occupational category: 2015



Note(s)

Scientists and engineers include those with one or more S&E or S&E-related degrees at the bachelor's level or higher or those who have only a non-S&E degree at the bachelor's level or higher and are employed in an S&E or S&E-related occupation. R&D activity refers to the share of workers reporting basic research, applied research, design, or development as a primary or secondary work activity in their principal job—activities ranking first or second in work hours.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Survey of College Graduates (NSCG) (2015), https://www.nsf.gov/statistics/srvygrads/.

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Most individuals in the S&E workforce who reported performing R&D have a bachelor’s (52%) or master’s (33%) degree as their highest degree; those with doctorates account for 12% of researchers but only 5% of the S&E workforce. In most occupations, those with doctorates indicated higher rates of R&D activity than those with a bachelor’s or master’s degree as their highest degree (Table 3-10).[7] Overall, among those employed in S&E occupations, about three-quarters of life and physical scientists reported R&D activity, whereas approximately half of social scientists (51%) and computer and mathematical scientists (45%) reported R&D activity (Table 3-10).

TABLE 3-10

R&D activity rate of scientists and engineers employed in S&E occupations, by broad occupational category and level of highest degree: 2015

(Percent)

Highest degree level	Biological, agricultural, and environmental life scientists	Computer and mathematical scientists	Physical scientists	Social scientists	Engineers
All degree levels	74.5	45.1	73.1	50.9	65.2
Bachelor's	65.1	44.7	64.3	53.3	63.3
Master's	76.3	43.2	70.6	51.0	65.0
Doctorate	83.1	71.8	84.9	52.7	85.0

Note(s)

R&D activity rate is the proportion of workers who report that basic research, applied research, design, or development is a primary or secondary work activity in their principal job—activities ranking first or second in work hours. Scientists and engineers include those with one or more S&E or S&E-related degrees at the bachelor's level or higher or those who have only a non-S&E degree at the bachelor's level or higher and are employed in an S&E or S&E-related field in 2015. All degree levels includes professional degrees not broken out separately.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Survey of College Graduates (NSCG) (2015), https://www.nsf.gov/statistics/srvygrads/.

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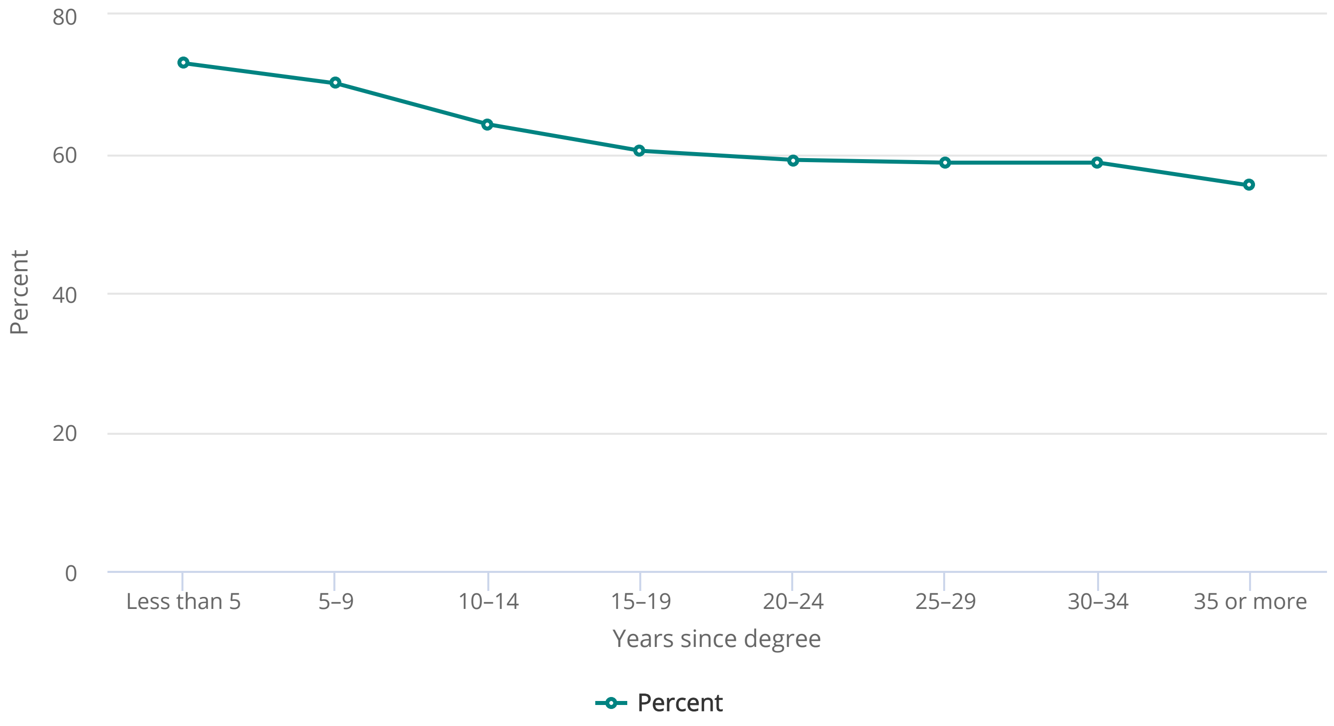
R&D activity tends to decline in later career stages (Figure 3-14). Among SEH doctorate holders who earned their doctorate in 2006 or later, 73% reported R&D activity in 2015. Among those receiving degrees between 1986 and 2005, 60% reported R&D activity in 2015. For those with degrees predating 1986, 56% reported R&D activity in 2015. The decline in R&D activity over the course of individuals' careers may reflect movement into teaching or management, growth of other career interests, or possession of scientific knowledge and skills that are no longer in demand. It may also reflect increased opportunity for more experienced scientists to perform functions involving the interpretation and use of, as opposed to the creation and development of, scientific knowledge.

FIGURE 3-14

Employed SEH doctorate holders with R&D activity, by years since doctoral degree: 2015



SEH = science, engineering, and health.

Note(s)

R&D activity refers to the share of workers reporting basic research, applied research, design, or development as a primary or secondary work activity in their principal job—activities ranking first or second in work hours.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Survey of Doctorate Recipients (SDR) (2015), https://www.nsf.gov/statistics/srvydoctoratework/.

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Work-Related Training

In addition to formal education, workers receive work-related training. Such training can contribute to innovation and productivity growth by enhancing skills, efficiency, and knowledge. In 2015, 52% of scientists and engineers reported participating in work-related training within the past 12 months of being surveyed (Table 3-11).[8] Among those who were employed, workers in S&E-related jobs (e.g., health-related occupations, S&E managers, S&E precollege teachers, and S&E technicians and technologists) exhibited higher rates of training (71%) than workers in S&E (54%) or non-S&E occupations (58%). Women participated in work-related training at a higher rate than men (55% versus 49%) (Appendix Table 3-6). This difference exists regardless of labor force status.

Among scientists and engineers who participated in such work-related training, most stated that their most important reason for participation was to improve skills or knowledge in their current occupational field (52%) (Appendix Table 3-7).[9] Others did so for licensure or certification in their current occupational field (20%) or because it was required or expected by their employer (19%). Relative to those who were employed or not in the labor force, those who were unemployed more frequently reported that they engaged in work-related training to facilitate a change to a different occupational field. Those who were not in the labor force more frequently reported that they engaged in this activity for leisure or personal interest than those who were in the labor force.

TABLE 3-11

Scientists and engineers participating in work-related training, by labor force status and occupation: 2015

(Number and percent)

Labor force status and occupation	Number	Percent
All scientists and engineers	16,243,000	52.1
Employed	15,431,000	61.0
S&E occupations	3,444,000	53.8
Biological, agricultural, and environmental life scientists	367,000	58.2
Computer and mathematical scientists	1,499,000	47.5
Physical scientists	175,000	52.9
Social scientists	379,000	66.5
Engineers	1,024,000	59.6
S&E-related occupations	5,585,000	71.0
Non-S&E occupations	6,104,000	58.0
Unemployed	282,000	32.5
S&E occupations	57,000	31.3
Biological, agricultural, and environmental life scientists	5,000	20.0
Computer and mathematical scientists	29,000	33.3
Physical and related scientists	3,000	27.9
Social and related scientists	13,000	64.1
Engineers	6,000	16.7
S&E-related occupations	63,000	43.4
Non-S&E occupations	162,000	32.5
Not in labor force	530,000	10.6

Note(s)

Scientists and engineers include those with one or more S&E or S&E-related degrees at the bachelor's level or higher or those who have only a non-S&E degree at the bachelor's level or higher and are employed in an S&E or S&E-related occupation in 2015. Unemployed individuals are those not working but who looked for a job in the preceding 4 weeks. For unemployed, the last job held was used for classification. Detail may not add to total because of rounding.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Survey of College Graduates (NSCG) (2015), https://www.nsf.gov/statistics/srvygrads/.

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[1] The data on self-employment from NSCG include those who report being self-employed or employed by a business owner in either an unincorporated or incorporated business, professional practice, or farm. As a result, the data may capture both self-employed individuals in their own businesses and those whose principal employer is a business owner. This is a major reason why the NSCG estimate of self-employed workers in S&E occupations is higher than those from other surveys (e.g., the Census Bureau's ACS).

[2] The source of the federal S&E employment data is OPM's Enterprise Human Resources Integration-Statistical Data Mart. Coverage is limited to federal civilian employees on pay status with certain exclusions. For information on specific exclusions and inclusions, see the coverage definition on OPM's Federal Human Resources Data (FedScope) Web page: https://www.fedscope.opm.gov/datadefn/aehri_sdm.asp#cpdf3.

[3] Employment in the federal government is largely limited to those with U.S. citizenship. Many federal workers with S&E employment are in occupations that, nationwide, include relatively large concentrations of foreign-born persons, some of whom are ineligible for many federal jobs because they are not U.S. citizens.

[4] This list does not include the National Institutes of Health, which is a part of the Department of Health and Human Services (HHS). S&E employment accounted for 19% of total HHS employment in 2016.

[5] The establishments in this sector provide professional, scientific, and technical services to clients in a variety of industries as well as households. The services provided by S&E workers in this industry sector may include computer services; engineering and specialized design services; consulting services; research services; advertising services; and other professional, scientific, and technical services.

[6] The other 10 activities are used to define four additional broad categories of primary or secondary work activities: teaching; management and administration; computer applications; and professional services, production workers, or other work activities not specified.

[7] Social scientists were exceptions. In 2015, a larger proportion of social scientists with doctorates reported R&D activity than social scientists with master's degrees; however, the difference in R&D activity rates between social scientists with doctorates and social scientists with bachelor's degrees was not statistically significant.

[8] Work-related training includes conferences and professional meetings only if the conference or meeting attendance also includes attending a training session. It does not include college coursework while enrolled in a degree program.

[9] Although NSCG respondents were allowed to provide more than one reason for participating in work-related training, the data presented in this section are the most important reason for participating in such training.

S&E Labor Market Conditions

This section assesses the overall health of the labor market for scientists and engineers. Indicators of labor market participation (such as rates of unemployment and working involuntarily out of one's degree field) and earnings provide meaningful information on economic rewards and the overall attractiveness of careers in S&E fields. Many labor market indicators are lagging indicators, which change some time after other indicators show that the economy has begun to follow a particular trend. For example, although the most recent recession officially began in December 2007 and ended in June 2009, unemployment rates continued to rise after the recession had officially ended.[1] Rates of unemployment, rates of working involuntarily out of one's field of highest degree, and earnings should all be considered in this context.

Unemployment

In general, unemployment rates among scientists and engineers tend to be lower than the rates for the labor force as a whole. In February 2015 (the reference month for the NSCG), an estimated 3.3% of scientists and engineers were unemployed (Appendix Table 3-8); the comparable unemployment rate for the entire U.S. labor force was higher, 5.8%.[2] Although the unemployment rate among scientists and engineers has gradually declined since the Great Recession, the rate in February 2015 continued to exceed the October 2006 (2.5%) pre-recession rate (Appendix Table 3-8). This shows clearly that the nation's S&E population, although somewhat sheltered, is not immune from fluctuations in broader economic conditions.

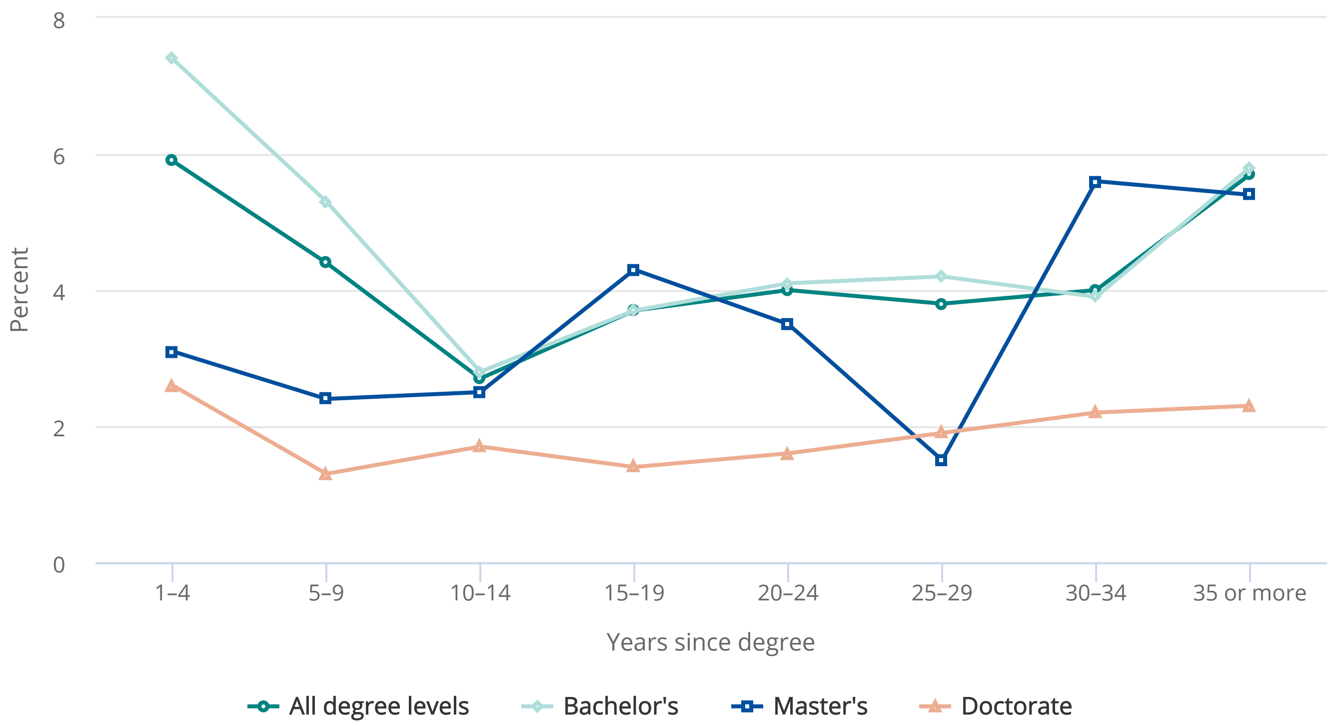
In 2015, unemployment rates varied across occupational categories. Among those in S&E occupations, unemployment rates ranged from 2.1% (among engineers) to 4.1% (among life scientists); among those in S&E-related and non-S&E occupations, the rate was 1.8% and 4.3%, respectively (Appendix Table 3-8). Additionally, advanced degree holders were generally less vulnerable to unemployment than those with only a bachelor's degree (Appendix Table 3-8).

The extent of unemployment also varies by career stages. S&E highest degree holders within 5–30 years after obtaining their highest degree were, for the most part, less likely to be unemployed than those at earlier points in their careers (Figure 3-15). As workers strengthen their skills by acquiring labor market experience and adding on-the-job knowledge to their formal training, their work situations become more secure. However, for those in the very late career stages (30 or more years after obtaining their highest degree), the unemployment rates turn higher than for those within 5–30 years after obtaining their highest degree. Growing selectivity about desirable work, skill obsolescence, and other factors may contribute to this phenomenon. The trends of lower unemployment during early- to mid-career stages compared with very early or very late stages hold for the bachelor's and doctoral degree levels, but not for the master's level (Figure 3-15).

CPS unemployment rates over the past two decades indicate that workers in S&E occupations have historically experienced lower unemployment rates than the overall labor force (Figure 3-16).[3] In addition, unemployment for all groups peaked after the 1990–91, 2001, and 2007–09 recessions, indicating once again that S&E workers are not immune from economic fluctuations.

FIGURE 3-15

Unemployment rates of S&E highest degree holders, by level of and years since highest degree: 2015



Note(s)

All degree levels includes professional degrees not shown separately. Detail may not add to total because of rounding.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Survey of College Graduates (NSCG) (2015), https://www.nsf.gov/statistics/srvygrads/, and the Survey of Doctorate Recipients (SDR) (2015), https://www.nsf.gov/statistics/srvydoctoratework/.

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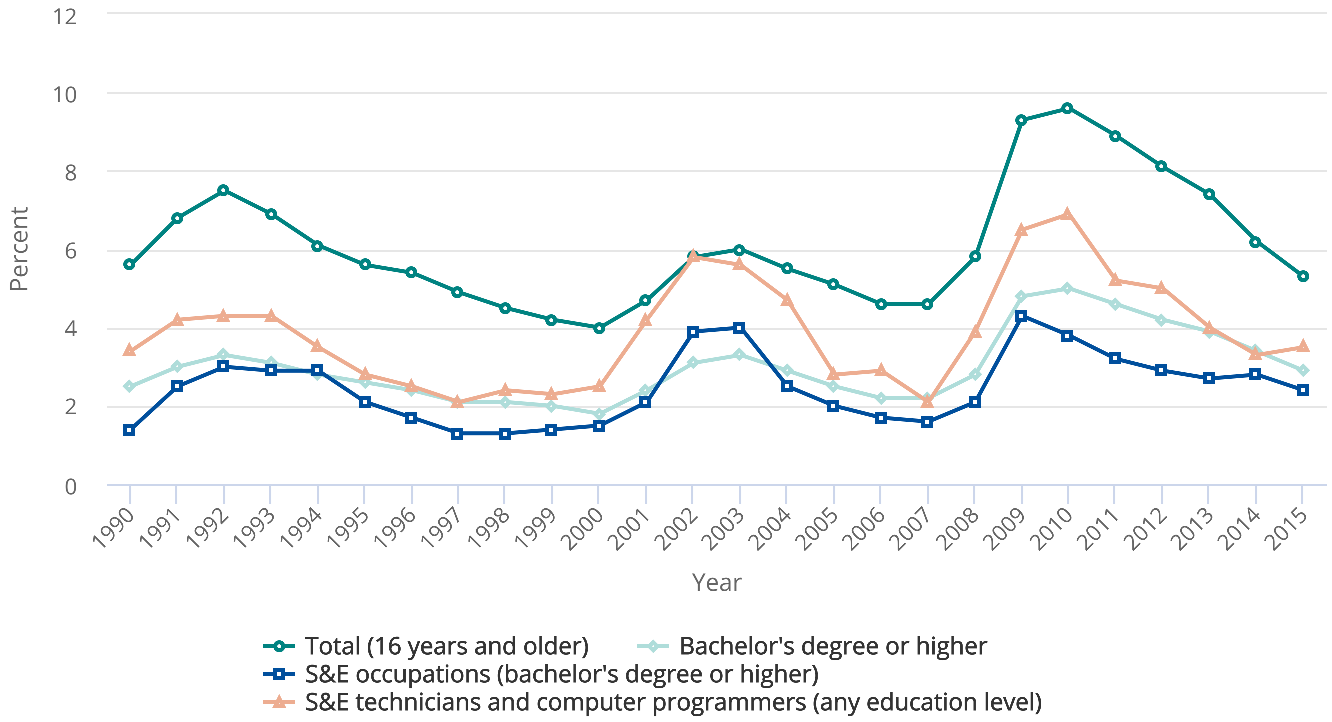
FIGURE 3-16

Unemployment rate, by selected groups: 1990–2015



Source(s)

National Bureau of Economic Research, Merged Outgoing Rotation Group files (1990–2015) and the Bureau of Labor Statistics, Current Population Survey (CPS).

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Working Involuntarily Out of One's Field of Highest Degree

Individuals invest time and financial resources in developing their knowledge and skills. Working outside of one's chosen field of education for involuntary reasons may create skills mismatches and economic inefficiencies that can be viewed as one indicator of labor market stress. Individuals work outside their highest degree field for a variety of reasons. Those who reported that they did so because suitable work was not available in their degree field are referred to here as involuntarily out-of-field (IOF) workers, and their number relative to all employed individuals is the IOF rate.

Of the 25 million employed scientists and engineers in 2015, almost 1.6 million reported working out of their field of highest degree because of a lack of suitable jobs in their degree field, yielding an IOF rate of 6.3%. For the more than 13.5 million whose highest degree was in an S&E field, the IOF rate was 7.9% (Table 3-12). NCSES survey respondents were allowed to provide more than one reason for working out of field. Other reasons cited by S&E degree holders included pay and promotion opportunities (reported by 1.8 million individuals), change in career or professional interests (1.2 million), working conditions (1.4 million), family-related reasons (751,000), job location (1.5 million), and other reasons (347,000). This suggests that, in addition to lack of a suitable job, various job-related and personal attributes such as compensation, location, and professional interest may result in out-of-field employment.

TABLE 3-12

Scientists and engineers who are working involuntarily out of field, by S&E degree field: Selected years, 2003–15

(Percent)

S&E degree field	2003	2006	2008	2010	2013	2015
All scientists and engineers	5.9	6.2	5.3	6.4	6.7	6.3
Highest degree in S&E field	7.8	8.1	7.1	8.4	8.3	7.9
Biological, agricultural, and environmental life sciences	10.1	9.7	10.1	10.1	9.4	10.4
Computer and mathematical sciences	4.9	5.7	4.5	5.1	4.1	4.0
Physical sciences	8.8	8.6	7.1	8.2	8.3	9.3
Social sciences	10.1	10.6	9.2	11.3	11.8	11.4
Engineering	4.2	4.5	3.6	4.9	4.6	3.2

Note(s)

Scientists and engineers include those with one or more S&E or S&E-related degrees at the bachelor's level or higher or those who have only a non-S&E degree at the bachelor's level or higher and are employed in an S&E or S&E-related occupation. The involuntarily out-of-field rate is the proportion of all employed individuals who report that their job is not related to their field of highest degree because a job in their highest degree field was not available.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Scientists and Engineers Statistical Data System (SESTAT) (2003–13), https://www.nsf.gov/statistics/sestat/, and the National Survey of College Graduates (NSCG) (2015), https://www.nsf.gov/statistics/srvygrads/.

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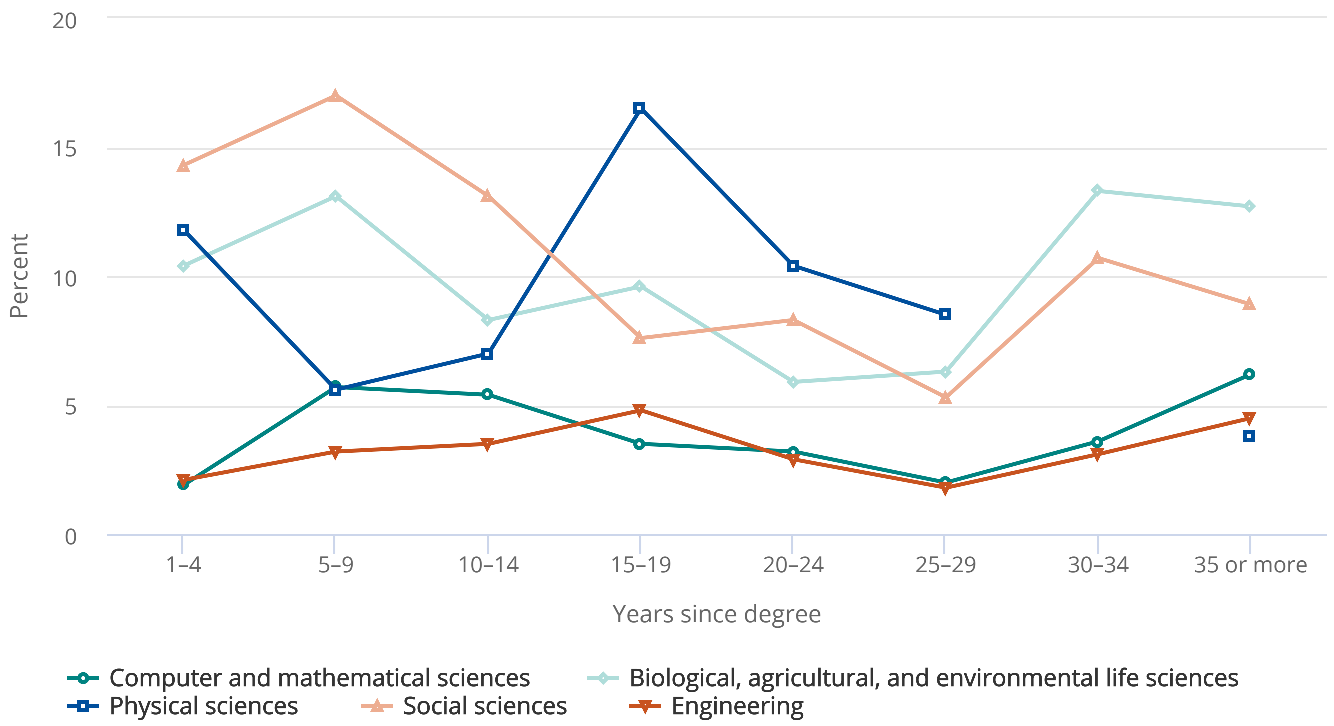
IOF rates vary by S&E degree fields and levels. Those with a highest degree in engineering or computer and mathematical sciences display lower IOF rates than those with a highest degree in physical, life, or social sciences (Table 3-12). The high IOF rates among social sciences degree holders, particularly in comparison with engineering and with computer and mathematical sciences degree holders, are evident across most of the career cycle (Figure 3-17). Additionally, S&E advanced degree holders are less likely to work IOF than those with S&E bachelor's degrees only: in 2015, the IOF rate was 1.8% among S&E doctorate holders, 4.2% among those with S&E master's degrees, and 9.7% among those with S&E bachelor's degrees.

FIGURE 3-17

S&E highest degree holders working involuntarily out of field, by field of and years since highest degree: 2015



Note(s)

Involuntarily out-of-field rate is the proportion of all employed individuals who reported working in a job not related to their field of highest degree because a job in that field was not available. Missing data have been suppressed for reasons of confidentiality and/or reliability.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Survey of College Graduates (NSCG) (2015), https://www.nsf.gov/statistics/srvygrads/.

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Earnings

According to the OES survey, individuals in S&E occupations earn considerably more than the overall workforce. The median annual salary in 2016 in S&E occupations (regardless of education level or field) was $83,900, which is more than double the median for all U.S. workers ($37,040) (Table 3-13). This reflects a high level of formal education and technical skills associated with S&E occupations. Median S&E salaries in 2013–16 rose at about the same rate (1.7%) as that for all U.S. workers (1.8%). In 2016, median salaries for workers in S&E occupations ranged from $73,060 for social scientists to $91,430 for engineers. Salaries for workers in S&E-related occupations displayed similar patterns of higher earnings relative to the overall workforce. Health-related occupations, the largest segment of S&E-related occupations, cover a wide variety of workers ranging from physicians, surgeons, and practitioners to nurses, therapists, pharmacists, and health technicians; as a result, these occupations display a large variation in salary levels (▦ Table 3-13).

TABLE 3-13

Annual salaries in science, technology, and related occupations: May 2013–May 2016

(Dollars)

Occupation	Mean			Median		
	Annual salaries in 2013	Annual salaries in 2016	Average annual growth rate 2013–16 (%)	Annual salaries in 2013	Annual salaries in 2016	Average annual growth rate 2013–16 (%)
All U.S. employment	46,440	49,630	2.2	35,080	37,040	1.8
STEM occupations	83,860	89,350	2.1	77,360	81,660	1.8
S&E occupations	84,400	89,750	2.1	79,670	83,900	1.7
Computer and mathematical scientists	81,830	87,890	2.4	77,710	82,780	2.1
Life scientists	80,770	84,660	1.6	71,490	73,270	0.8
Physical scientists	84,730	88,220	1.4	75,680	78,210	1.1
Social scientists	74,230	81,070	3.0	68,310	73,060	2.3
Engineers	92,770	97,170	1.6	87,640	91,430	1.4
Technology occupations	80,500	86,390	2.4	66,430	70,070	1.8
S&E-related occupations (not listed above)	76,200	81,140	2.1	62,600	65,050	1.3
Health-related occupations	76,120	81,070	2.1	62,370	64,820	1.3
Registered nurses	68,910	72,180	1.6	66,220	68,450	1.1
Dentists, general	164,570	173,860	1.8	146,340	153,900	1.7
Family and general practitioners	183,940	200,810	3.0	176,530	190,490	2.6
Other S&E-related occupations	81,040	85,280	1.7	73,740	76,310	1.1
Non-STEM occupations	41,700	44,450	2.2	31,940	33,840	1.9
Chief executives	178,400	194,350	2.9	171,610	181,210	1.8
General and operations manager	116,090	122,090	1.7	96,430	99,310	1.0

Occupation	Mean			Median		
	Annual salaries in 2013	Annual salaries in 2016	Average annual growth rate 2013–16 (%)	Annual salaries in 2013	Annual salaries in 2016	Average annual growth rate 2013–16 (%)
Education administrators, postsecondary	100,600	102,610	0.7	87,410	90,760	1.3
Management analysts	89,990	91,910	0.7	79,870	81,330	0.6
Financial analysts	91,620	97,640	2.1	78,380	81,760	1.4
Lawyers	131,990	139,880	2.0	114,300	118,160	1.1
Technical writers	70,290	73,160	1.3	67,900	69,850	0.9

STEM = science, technology, engineering, and mathematics.

Note(s)

See Table 3-2 for classifications of S&E, S&E-related, and STEM occupations. Occupational Employment Statistics (OES) survey employment data do not cover employment in some sectors of the agriculture, forestry, fishing, and hunting industry; in private households; or among self-employed individuals. As a result, the data do not represent total U.S. employment.

Source(s)

Bureau of Labor Statistics, special tabulations (2014 and 2017) of May 2013 and May 2016 OES Survey.

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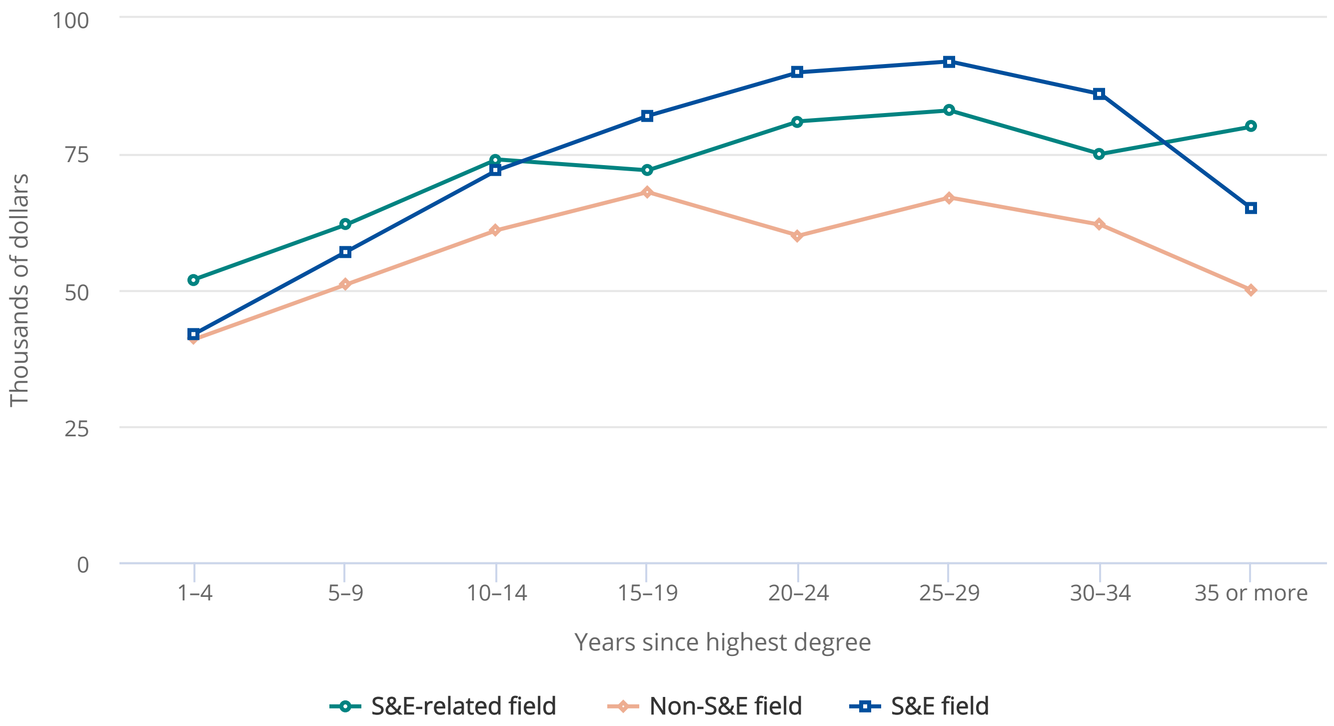
Overall, college-educated individuals with an S&E or S&E-related degree enjoy an earnings premium compared to those with a non-S&E degree; for the most part, this earnings premium is present across career stages. Figure 3-18 presents data on median salaries for groups with S&E, S&E-related, or non-S&E highest degrees at comparable numbers of years since receiving their highest degrees. Although median salaries are similar in the beginning for S&E and non-S&E degree holders, and both are lower than the median salary for S&E-related degree holders, the rise in earnings associated with career progression is much steeper among individuals with S&E degrees. Among S&E highest degree holders, those with engineering or computer and mathematical sciences degrees earn more than degree holders in other broad S&E fields during early to mid-career stages; engineering degree holders continue to enjoy an earnings premium through later career stages compared with their counterparts with degrees in most other broad S&E fields (Figure 3-19).

FIGURE 3-18

Median salaries for employed, college-educated individuals, by broad field of and years since highest degree: 2015



Note(s)

See Table 3-2 for classification of S&E, S&E-related, and non-S&E degree fields.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Survey of College Graduates (NSCG) (2015), https://www.nsf.gov/statistics/srvygrads/.

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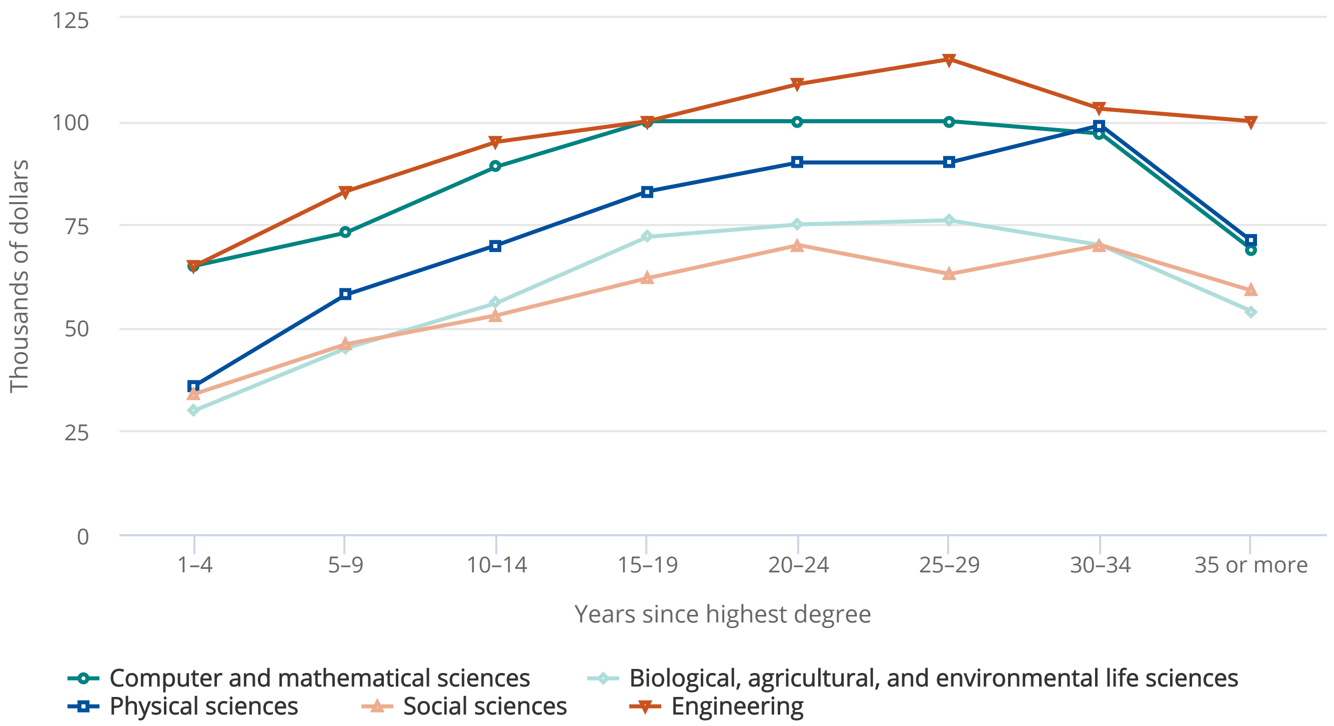
FIGURE 3-19

Median salaries for S&E highest degree holders, by broad field of and years since highest degree: 2015



Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Survey of College Graduates (NSCG) (2015), https://www.nsf.gov/statistics/srvygrads/.

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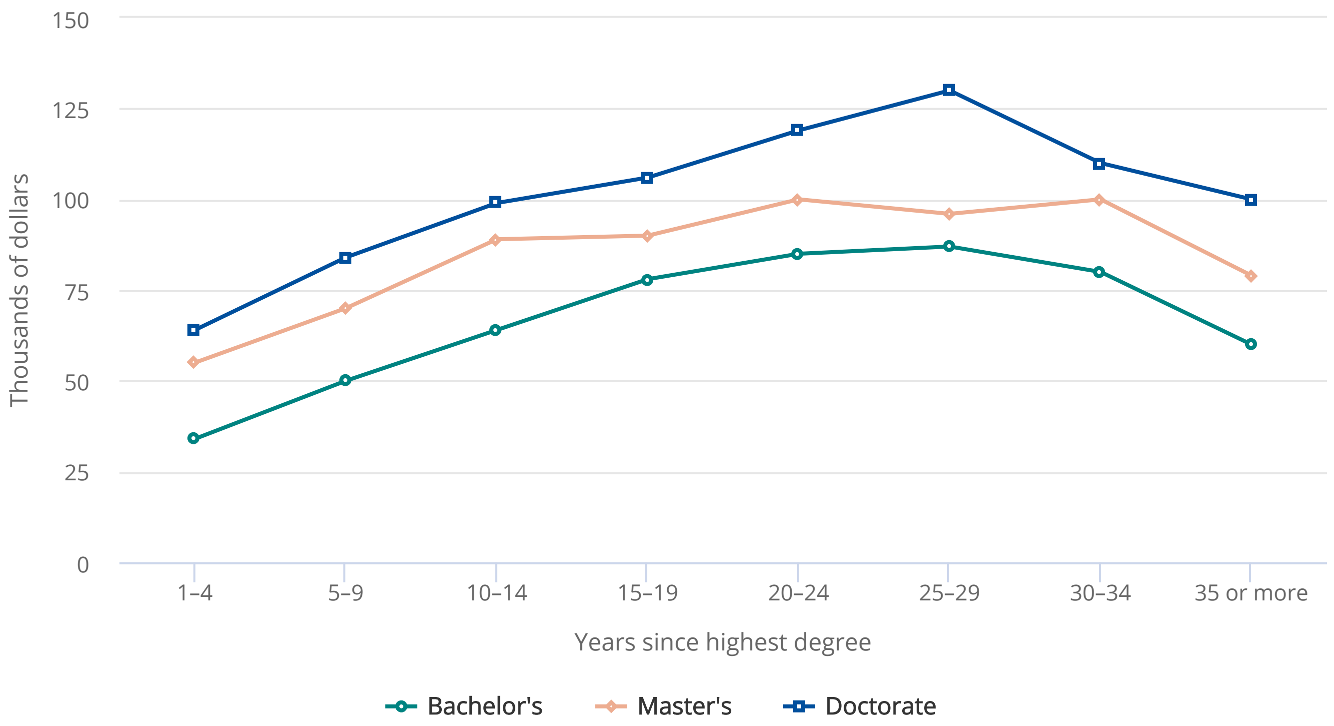
Earnings also vary by degree levels. For those with an S&E highest degree, annual median salaries are higher with a master's or doctoral degree (Appendix Table 3-9), and this pattern holds across career stages (Figure 3-20). Among all occupations, those with an S&E-related or non-S&E highest degree, professional degree holders earn the most (Appendix Table 3-9). The relatively high median salaries among S&E-related or non-S&E professional degree holders are driven primarily by medical practitioners and lawyers, respectively. A majority of college graduate workers whose highest degree is a professional degree in an S&E-related field (68%) work as a diagnosing or treating practitioner (with a median salary of $139,000); a majority of those whose highest degree is a professional degree in a non-S&E field (77%) work as a lawyer or judge (with a median salary of $124,000).

FIGURE 3-20

Median salaries for S&E highest degree holders, by level of and years since highest degree: 2015



Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Survey of College Graduates (NSCG) (2015), https://www.nsf.gov/statistics/srvygrads/.

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Among employed individuals without a bachelor’s degree, workers in S&E occupations have more stable jobs with higher salaries than those in non-S&E occupations. (See sidebar A Broader Look at the S&E Workforce.)

SIDEBAR

A Broader Look at the S&E Workforce

Although National Center for Science and Engineering Statistics (NCSES) data provide detailed information on college-graduate scientists and engineers, NCSES lacks similar data on individuals whose highest level of education is either high school, some college, or a 2-year degree. Sometimes referred to as the “sub-baccalaureate,” “career and technical,” or the “skilled technical” workforce (as used herein), these workers employ significant levels of S&E and technical knowledge in their jobs and are a considerable segment of the overall S&E workforce in the United States. This sidebar presents nationally representative data from the Census Bureau’s American Community Survey (ACS) on employment trends among this group, showing solid career opportunities with lower unemployment rates and higher salaries than their non-S&E counterparts. About 6.1 million skilled technical workers age 25 and older were employed in an S&E or S&E-related occupation in 2015.*

The skilled technical workforce accounts for a considerable part of S&E employment in the United States—about one-quarter of all S&E jobs (1.6 million) and 40% of all S&E-related jobs (4.5 million) in 2015. About 13% of skilled technical workers in these occupations were black, 10% were Hispanic, 4% were Asian, and about 11% were foreign born. The corresponding shares among college-educated workers in S&E or S&E-related occupations were 7% black, 6% Hispanic, 17% Asian, and 24% foreign born. Thus, in terms of demographic composition, skilled technical workers were more likely to be black or Hispanic than their counterparts with bachelor’s degrees.

Skilled technical workers were employed in large numbers in computer occupations and health occupations. Among the 1.6 million skilled technical workers employed in S&E occupations, 69% were concentrated in computer occupations; computer support specialists accounted for the largest subset (27%) of these workers. In comparison, 47% of the college-educated workers in S&E occupations held computer jobs; software developers represented the largest subset (41%) of these workers.

Health occupations accounted for the largest subset of workers in S&E-related occupations (74%). However, skilled technical workers were concentrated in different categories of health occupations than those with a bachelor’s degree. For example, about 60% of health workers at the sub-baccalaureate degree level of educational attainment were employed as health technicians or technologists; only 13% of health workers with a college degree were employed in these occupations. Conversely, a larger proportion of health workers with a college degree were employed as registered nurses (61% with a bachelor’s degree or higher and 40% of sub-baccalaureate workers, respectively).

Relative to other occupations, S&E and S&E-related occupations provide sound employment for workers at the sub-baccalaureate degree level. In 2015, the median earnings of skilled technical workers in S&E ($60,000) or S&E-related ($45,000) occupations were significantly higher than the median earnings in other occupations ($29,000). The unemployment rate among these workers in S&E (4%) or S&E-related (3%) occupations was lower than the rate in other occupations (7%). Among skilled technical workers in S&E or S&E-related occupations, median salaries ranged from about $35,000 among health care technicians and technologists to $50,000 among S&E technicians, $51,000 among registered nurses, and $60,000 among computer workers. The unemployment rate ranged from 2% among registered nurses to 3% among health care technicians and 4% among computer workers and S&E technicians.

Workers employed in S&E or S&E-related occupations received more formal training (even if they did not have a bachelor’s degree) than those employed in other occupations; therefore, it is not surprising that salaries were higher in these jobs. Among skilled technical workers, 69% of those employed in S&E occupations and 73% of those employed in

S&E-related occupations had an associate's degree or 1 or more years of college credit, compared to 36% of those employed in other occupations.

* This sidebar defines the S&E workforce by workers in S&E occupations (except postsecondary teachers in S&E fields). The ACS data do not allow for separate identification of postsecondary teachers by fields. See Appendix Table 3-1 for a list of S&E occupations in the 2015 ACS.

Recent S&E Graduates

In today's knowledge-based and globally integrated economy—marked by rapid information flow and development of new knowledge, products, and processes—demand for certain skills and abilities may change fast. The employment outcomes of recent graduates are an important indicator of current changes in labor market conditions. Compared with experienced S&E workers, recent S&E graduates more often bring new ideas and newly acquired skills to the labor market. This section examines the employment outcomes of recent recipients of S&E bachelor's, master's, and doctoral degrees.

General Labor Market Indicators for Recent Graduates

Table 3-14 summarizes some basic labor market statistics in 2015 for recent recipients of S&E degrees. *Recent* here is defined as between 1 and 5 years since receiving the highest degree. Among the over 25 million scientists and engineers employed in February 2015, 2.6 million were recent S&E degree recipients. Overall, the unemployment rate among recent S&E graduates was 5.6%, compared with the 3.3% unemployment rate overall among scientists and engineers.

Among recent bachelor's degree holders, the unemployment rate averaged 6.8%, ranging from about 3% for those with computer and mathematical sciences degrees to 12.1% for those with biological, agricultural, and environmental life sciences degrees. Overall, unemployment was generally lower for those with recent doctorates and master's degrees than for those with recent bachelor's level degrees. Early in their careers, as individuals gather labor market experience and on-the-job skills, they tend to have a higher incidence of job change and unemployment, which may partially explain some of the higher unemployment rates seen among those with a bachelor's degree as their highest degree.

A useful but more subjective indicator of labor market conditions for recent graduates is the proportion who report that their job is unrelated to their highest degree field because a job in their degree field was not available (i.e., the IOF rate). Of the nearly 2.6 million employed scientists and engineers who received their highest degree in an S&E field in the previous 5 years, an estimated 10.4% indicated working involuntarily out of field in 2015 (Table 3-14). Therefore, the IOF rate among recent S&E degree recipients in 2015 was higher than the IOF rate among all S&E highest degree holders (7.9%). NSF survey respondents were allowed to report more than one reason for working out of field, as well as the most important reason for working out of field. When asked about the most important reason for working out of field, the reasons most frequently cited by recent S&E degree recipients were lack of a suitable job in their degree field (cited by 32% of those working out of field), followed by pay and promotion opportunities (18%) and change in career or professional interests (14%). The responses provided by all S&E highest degree holders working out of field (regardless of graduation year) were similar, but the factors were ranked differently: the most frequently cited reasons were pay and promotion opportunities (cited by 24% of all S&E highest degree holders working out of field), followed by change in career or professional interests (19%) and lack of a suitable job in their degree field (19%).

IOF rates vary across S&E degree levels and fields. Overall, IOF rates are lower among advanced degree holders compared with those with only bachelor's level degrees, but significant variation exists across degree fields. Among recent bachelor's degree holders, the IOF rate ranged from 3.9% among recent engineering graduates to 19.4% among recent graduates in the social sciences (Table 3-14). Among recent bachelor's degree holders in social sciences, IOF rates were high in most major fields, including political sciences, psychology, and sociology and anthropology.

The median salary for recent S&E bachelor's degree recipients in 2015 was $37,000, ranging from $30,000 in life sciences and physical sciences to $62,000 in engineering (Table 3-14). Recent master's degree recipients had a median salary of $58,000, and recent doctorate recipients had a median salary of $66,000.

TABLE 3-14

Labor market indicators for recent S&E degree recipients up to 5 years after receiving degree, by level and field of highest degree: 2015

(Percent and dollars)

Indicator and highest degree level	All S&E fields	Biological, agricultural, and environmental life sciences	Computer and mathematical sciences	Physical sciences	Social sciences	Engineering
Unemployment rate (%)						
All degree levels	5.6	9.2	2.3	4.7	5.3	5.4
Bachelor's	6.8	12.1	2.9	s	5.7	s
Master's	2.8	1.9	s	s	4.6	2.5
Doctorate	2.5	s	s	s	2.4	s
Involuntarily out-of-field (IOF) rate (%)						
All degree levels	10.4	11.3	3.3	11.9	16.2	3.2
Bachelor's	13.3	15.0	4.1	15.1	19.4	3.9
Master's	4.9	s	2.9	s	7.7	2.5
Doctorate	0.6	s	s	s	s	s
Median annual salary ($)						
All degree levels	43,000	31,000	61,000	39,000	35,000	66,000
Bachelor's	37,000	30,000	50,000	30,000	32,000	62,000
Master's	58,000	30,000	79,000	50,000	46,000	75,000
Doctorate	66,000	46,000	100,000	50,000	66,000	98,000

s = suppressed for reasons of confidentiality and/or reliability.

Note(s)

Median annual salaries are rounded to the nearest $1,000. All degree levels includes professional degrees not broken out separately. Data include degrees earned from February 2010 to February 2014. The IOF rate is the proportion of all employed individuals who report that their job is not related to their field of highest degree because a job in their highest degree field was not available.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Survey of College Graduates (NSCG) (2015), https://www.nsf.gov/statistics/srvygrads/.

Science and Engineering Indicators 2018

Recent Doctorate Recipients

The career rewards of highly skilled individuals in general, and of doctorate holders in particular, often extend beyond salary and employment to the more personal rewards of doing the kind of work for which they have trained. No single standard measure satisfactorily reflects the state of the doctoral S&E labor market. This section discusses a range of relevant labor market indicators, including unemployment rates, IOF employment, employment in academia compared with other sectors, employment in postdoctoral positions, and salaries. Although a doctorate can expand career and salary opportunities, these opportunities may come at the price of many years of lost labor market earnings due to the number of years required to earn the degree.

Unemployment. In February 2015, the unemployment rate for SEH doctorate recipients up to 3 years after receiving their doctorates was 2.7% (▦ Table 3-15), compared to an unemployment rate of 1.8% for all SEH doctorates. The unemployment rate for recent SEH doctorate recipients was also lower than the unemployment rate for the entire population of scientists and engineers, regardless of level or year of award of highest degree (3.3%).

TABLE 3-15

Employment characteristics of recent SEH doctorate recipients up to 3 years after receiving doctorate, by field of degree: 2001–15

(Number and percent)

Field of doctorate	Recent doctorates (number)							Unemployment rate (%)							Involuntarily out-of-field (IOF) rate (%)						
	2001	2003	2006	2008	2010	2013	2015	2001	2003	2006	2008	2010	2013	2015	2001	2003	2006	2008	2010	2013	2015
All recent SEH doctorates	48,700	43,700	49,500	52,600	52,700	45,500	49,400	1.3	2.5	1.2	1.5	2.3	2.7	2.7	2.8	2.1	1.4	1.3	1.8	2.3	1.7
Biological, agricultural, and environmental life sciences	12,300	11,200	12,600	13,400	14,100	12,200	12,900	1.4	2.4	0.9	1.7	1.5	3.4	3.2	2.6	1.0	0.3	1.0	1.5	2.6	0.8
Computer and information sciences	1,600	1,400	1,500	2,400	2,500	2,000	2,400	0.3	4.1	1.9	s	s	s	s	s	s	2.6	1.4	s	s	s
Mathematics and statistics	2,200	1,600	2,000	2,400	2,400	2,200	2,600	0.2	3.4	s	s	s	s	s	1.4	3.4	2.2	1.1	s	s	s
Physical sciences	7,700	6,500	7,400	7,500	7,700	6,400	6,900	1.5	1.3	1.1	3.0	2.6	4.8	4.4	5.4	4.2	2.6	2.3	1.4	1.7	3.0
Psychology	7,200	6,300	7,000	5,800	5,400	4,700	5,000	1.5	2.7	1.2	0.8	3.8	s	2.0	3.0	1.5	1.4	0.8	2.0	s	2.1
Social sciences	5,800	6,000	6,200	5,900	6,000	5,400	6,100	1.6	3.1	1.4	2.1	3.4	3.8	1.7	3.3	3.0	2.3	3.4	3.5	5.9	3.4
Engineering	9,400	8,000	9,500	12,000	11,300	9,600	10,300	1.5	3.0	1.8	1.2	2.7	2.1	3.0	2.0	3.0	1.6	0.7	1.9	2.2	2.0
Health	2,400	2,700	3,200	3,300	3,400	3,000	3,200	0.4	0.7	0.9	1.2	s	s	3.1	s	1.1	s	s	s	s	s

s = suppressed for reasons of confidentiality and/or reliability.

SEH = science, engineering, and health.

Note(s)

IOF rate is the proportion of all employed individuals who report working in a job not related to their field of doctorate because a job in that field was not available. Data for 2001 and 2006 include graduates from 12 months to 36 months prior to the survey reference date; data for 2003, 2008, and 2010 include graduates from 15 months to 36 months prior to the survey reference date; data for 2013 and 2015 include graduates from 19 months to 36 months prior to the survey reference date. Detail may not add to total because of rounding.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Survey of Doctorate Recipients (SDR) (2001–15), https://www.nsf.gov/statistics/srvydoctoratework/.

Science and Engineering Indicators 2018

Working involuntarily out of field. About 1.7% of employed recent SEH doctorate recipients reported that they took a job that was not related to the field of their doctorate because a suitable job in their field was not available (Table 3-15). This was relatively better than the IOF rate for all S&E highest degree holders (7.9%).

Tenure-track positions. Although many science doctorate recipients aspire to tenure-track academic appointments (Sauermann and Roach 2012), most end up working in other types of positions and sectors. In 2015, about 14% of those who had earned their SEH doctorate within the previous 3 years had a tenured or tenure-track faculty appointment (Table 3-16).[4] Across the broad SEH fields, this proportion varied significantly, from less than 10% among recent doctorates in life sciences, physical sciences, and engineering to 38% among those in the social sciences.

The proportion of SEH doctorates who hold a tenured or tenure-track faculty appointment increases with years of experience. In 2015, 18% of SEH doctorates in the labor market for 3–5 years had tenure or a tenure-track appointment, compared with 14% of their colleagues who were within 3 years of doctorate receipt (Table 3-16). The extent of the increase varies across the broad areas of training. In the social sciences, for example, a relatively large percentage of individuals obtain a tenured or tenure-track position within 3 years of earning their doctorate, and the percentage associated with 3–5 years of labor market exposure remains similar; in others fields, such as physical sciences or engineering, this percentage increases. (See Chapter 5 for an in-depth discussion of various types of academic positions held by S&E doctorate holders.)

TABLE 3-16

Employed SEH doctorate recipients holding tenured and tenure-track appointments at academic institutions, by field of and years since degree: Selected years, 1993–2015

(Percent)

Years since doctorate and field	1993	1995	1997	1999	2001	2003	2006	2008	2010	2013	2015
Less than 3 years											
All SEH fields	18.1	16.3	15.8	13.5	16.5	18.6	17.7	16.2	14.7	12.4	14.4
Biological, agricultural, and environmental life sciences	9.0	8.5	9.3	7.7	8.6	7.8	7.2	6.5	7.6	5.3	5.0
Computer and information sciences	31.5	36.5	23.4	18.2	20.7	32.5	31.2	22.0	20.8	21.1	20.8
Mathematics and statistics	40.9	39.8	26.9	18.9	25.2	38.4	31.6	31.3	26.1	25.0	19.2
Physical sciences	8.8	6.9	8.5	7.8	10.0	13.3	9.8	8.8	6.8	6.9	6.2
Psychology	12.8	13.6	14.7	16.0	15.6	14.6	17.0	18.1	16.0	11.1	17.0
Social sciences	43.5	35.9	37.4	35.4	38.5	44.8	39.3	45.4	41.1	38.0	37.9
Engineering	15.0	11.5	9.4	6.4	11.3	10.8	12.4	9.3	7.5	6.6	8.2
Health	33.9	34.2	30.1	28.1	32.1	30.3	36.2	27.7	24.2	20.7	25.8
3–5 years											
All SEH fields	27.0	24.6	24.2	21.0	18.5	23.8	25.9	22.9	19.7	19.4	17.7
Biological, agricultural, and environmental life sciences	17.3	17.0	18.1	16.4	14.3	15.5	13.7	14.3	10.6	10.6	8.1
Computer and information sciences	55.7	37.4	40.7	25.9	17.3	32.2	45.7	37.8	22.2	13.8	23.3
Mathematics and statistics	54.9	45.5	48.1	41.0	28.9	45.5	50.6	40.7	41.7	29.6	23.1
Physical sciences	18.8	15.5	14.5	11.9	15.8	18.3	19.7	16.5	14.7	14.3	16.1
Psychology	17.0	20.7	16.8	17.6	17.5	19.9	23.8	18.3	19.1	17.6	22.4
Social sciences	54.3	52.4	50.4	46.5	38.8	46.0	50.4	48.9	46.7	48.5	38.0
Engineering	22.7	19.3	19.4	12.6	10.8	15.9	16.3	15.5	13.0	14.6	11.3
Health	47.4	40.2	41.1	39.5	25.1	40.8	43.1	34.4	33.3	32.4	30.6

SEH = science, engineering, and health.

Note(s)

Proportions are calculated on the basis of all doctorate recipients working in all sectors of the economy. Data for 1993–99, 2001, and 2006 include graduates from 12 months to 60 months prior to the survey reference date; data for 2003, 2008, and 2010 include graduates from 15 months to 60 months prior to the survey reference date; data for 2013 and 2015 include graduates from 19 months to 60 months prior to the survey reference date.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Survey of Doctorate Recipients (SDR) (1993–2015), https://www.nsf.gov/statistics/srvydoctoratework/.

Science and Engineering Indicators 2018

Desirable nonacademic employment opportunities may provide an alternative career path to that of a tenured or tenure-track appointment. Among recent doctorates in most S&E fields, median salaries are significantly higher in the business sector than in tenured or tenure-track academic positions (▦ Table 3-17). The proportion of recent graduates who obtain tenure or tenure-track employment has declined since 1993 in a number of broad areas of SEH training (▦ Table 3-16). One of the steepest declines occurred in computer sciences, particularly among individuals within 3–5 years of receiving their doctorates, despite the high demand for computer sciences faculty.

Salaries for recent SEH doctorate recipients. For all SEH degree fields in 2015, the median annual salary for recent doctorate recipients within 5 years after receiving their degrees was $74,000 (▦ Table 3-17). Across various SEH degree fields, median annual salaries ranged from a low of $54,000 in biological sciences to a high of $114,000 in computer and information sciences. Between 2013 and 2015, median salaries increased overall among recent recipients of SEH doctorates; the median salary for recent SEH doctorate recipients in 2013 was $70,000.

By type of employment, salaries for recent doctorate recipients ranged from $47,000 for postdoctoral positions in 4-year institutions to $99,000 for those employed in the business sector (▦ Table 3-17). Each sector, however, exhibited substantial internal variation by SEH fields of training.

TABLE 3-17

Median salaries for recent SEH doctorate recipients up to 5 years after receiving degree, by field of degree and employment sector: 2015

(Dollars)

Field of doctorate	All sectors	Education				Government	Business or industry
		4-year institutions			2-year or precollege institutions		
		All positions	Tenured or tenure-track position	Postdoc			
All SEH fields	74,000	57,000	72,000	47,000	54,000	82,000	99,000
Biological, agricultural, and environmental life sciences	54,000	48,000	68,000	46,000	44,000	65,000	77,000
Computer and information sciences	114,000	80,000	84,000	63,000	s	102,000	137,000
Mathematics and statistics	77,000	57,000	62,000	53,000	s	99,000	114,000
Physical sciences	72,000	53,000	69,000	48,000	50,000	82,000	95,000
Psychology	67,000	60,000	66,000	47,000	65,000	82,000	76,000
Social sciences	68,000	63,000	69,000	50,000	62,000	85,000	95,000
Engineering	95,000	68,000	83,000	48,000	44,000	93,000	104,000
Health	80,000	74,000	80,000	45,000	s	89,000	96,000

s = suppressed for reasons of confidentiality and/or reliability.

SEH = science, engineering, and health.

Note(s)

Salaries are rounded to the nearest $1,000. Data include graduates from 19 months to 60 months prior to the survey reference date. The 2-year or precollege institutions include 2-year colleges and community colleges or technical institutes and also preschool, elementary, middle, or secondary schools. The 4-year institutions include 4-year colleges or universities, medical schools, and university-affiliated research institutes.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Survey of Doctorate Recipients (SDR) (2015), https://www.nsf.gov/statistics/srvydoctoratework/.

Science and Engineering Indicators 2018

Postdoctoral Positions

A significant number of new S&E doctorate recipients take a postdoctoral appointment (generally known as a postdoc) as their first position after receiving their doctorate. Postdoc positions are defined as temporary, short-term positions, primarily for acquiring additional training in an academic, a government, an industry, or a nonprofit setting.[5] In many S&E disciplines, a postdoc position is generally expected to be competitive for obtaining a faculty position.

Individuals in postdoc positions often perform cutting-edge research and receive valuable training. These positions, however, generally offer lower salaries than permanent positions. A factor that has received much attention in science policy is the growth seen over the last three decades in the number of postdocs in both traditional (e.g., life sciences and physical sciences) and nontraditional (e.g., social sciences and engineering) academic disciplines and in an environment where the availability of research-intensive academic positions—the type of jobs for which postdocs are typically trained—have not risen at a similar pace (ACS 2013; NAS/NAE/IOM 2000, 2014; NIH 2012). Neither the reasons for this growth nor its effects on the state of scientific research are well understood. However, possible contributing factors include increases in competition for tenure-track academic research jobs, the need for collaborative research in large teams, the influx of graduate students in SEH areas with strong postdoc traditions, and the need for additional specialized training.

Number of postdocs. The estimated number of postdocs varies depending on the data source used. No single data source measures the entire population of postdocs. Three NSF surveys—the SDR, the Survey of Graduate Students and Postdoctorates in Science and Engineering, and the Early Career Doctorates Survey (ECDS)[6] —include data related to the number of postdocs in the United States. The three surveys overlap in some populations (such as U.S.-trained doctorate holders and those working in academia) but differ in others. For instance, the SDR covers U.S.-trained postdocs in all sectors—academic, industry, and government—whereas the Survey of Graduate Students and Postdoctorates in Science and Engineering and the ECDS cover both U.S.- and foreign-trained doctorate holders in academia but not all postdocs in the industry and government sectors.[7] In addition, the titles of postdoc researchers vary across organizations and often change as individuals advance through their postdoc appointments; both factors further complicate the data collection process (NIH 2012).

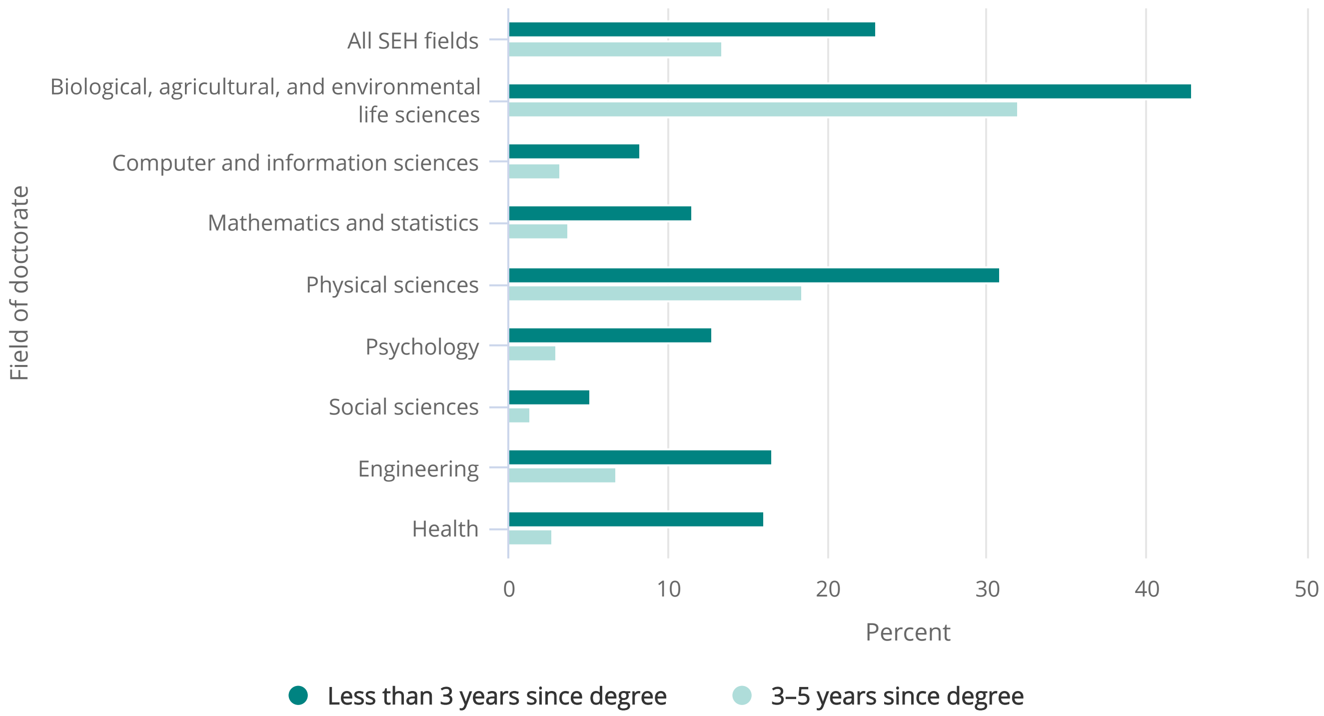
The SDR estimated that 26,700 U.S. SEH doctorate recipients in 2015 were employed in postdoc positions. The majority of these postdoc positions were in 4-year academic institutions (72%), with the remainder in the business sector (19%) and government sector (9%). Within the business sector, nonprofit organizations accounted for most of the postdoc positions. The estimated totals from NCSES's Survey of Graduate Students and Postdoctorates in Science and Engineering and the ECDS are significantly higher: 63,900 and 69,600, respectively, in 2015 (Arbeit and Kang 2017; NSF/NCSES 2017; Phou 2017). Both the SDR and the Survey of Graduate Students and Postdoctorates in Science and Engineering report increases in the number of postdocs since 2003. The SDR reported 30,800 postdocs in 2010 and 19,800 over a decade earlier in 2003, while the Survey of Graduate Students and Postdoctorates in Science and Engineering gives past totals of postdocs at 63,400 in 2010 and 46,700 in 2003.

Postdocs by academic discipline. Although postdocs are increasingly common in SEH fields, the extent to which a postdoc appointment is part of an individual's career path varies greatly across SEH fields. Postdocs have historically been more common in life sciences and physical sciences than in other fields such as social sciences and engineering. Among new doctorate recipients in 2015, 63% in life sciences (including agricultural sciences and natural resources, biological and biomedical sciences, and health sciences) and 64% in physical sciences indicated they would take a postdoc appointment, compared to 38% in psychology and social sciences and 36% in engineering (Appendix Table 3-10).[8] However, in life sciences and physical sciences, the proportion of new doctorate recipients indicating that they would take a postdoc position rose significantly between the mid-1970s and the mid-1990s and has fluctuated within a relatively narrow range since then. In the social sciences, the comparable proportion has continued to rise gradually since the early 1970s. In engineering, the comparable proportion has risen overall between 1975 and 2015, despite periodic fluctuations within this 40-year period.

Another indicator of the variation in postdoc appointments across S&E disciplines is the proportion of recent graduates who are currently employed as a postdoc (as opposed to those who plan to take a postdoc position after graduation). In 2015, over 40% of those who had received their doctorates in the previous 3 years in biological, agricultural, and environmental life sciences and nearly one-third in physical sciences (31%) were employed in postdoc positions, compared to only 5% of those who received doctorates in the social sciences (Figure 3-21).

FIGURE 3-21

Recent U.S. SEH doctorate recipients in postdoc positions, by field of and years since doctorate: 2015



SEH = science, engineering, and health.

Note(s)

Proportions are calculated on the basis of all doctorates working in all sectors of the economy. Data include graduates from 19 months to 60 months prior to the survey reference date (February 2013). Data for computer and information sciences doctorates are suppressed for reasons of confidentiality and/or reliability.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Survey of Doctorate Recipients (SDR) (2015), https://www.nsf.gov/statistics/srvydoctoratework/.

Science and Engineering Indicators 2018

Postdoc compensation. Low compensation for postdocs is frequently raised as a concern by those who are worried about the effect of the increasing number of postdoc positions on the attractiveness of science careers. In 2015, among individuals who had received their doctorate within the past 5 years, the median salary for postdocs ($47,000) was just over half the median salary for individuals in other positions (i.e., non-postdoc positions) ($82,000) (Table 3-18). The difference in median salary between postdocs and non-postdocs ranged from about half among individuals with doctorates in engineering (52%) and computer and information sciences (53%) to over two-thirds among those with doctorates in the biological, agricultural, and environmental life sciences (69%).

TABLE 3-18

Median salaries for recent U.S. SEH doctorate recipients in postdoc and non-postdoc positions up to 5 years after receiving degree: 2015

(Dollars)

Field of doctorate	All positions	Postdocs	Non-postdocs
All SEH	74,000	47,000	82,000
Biological, agricultural, and environmental life sciences	54,000	46,000	67,000
Computer and information sciences	114,000	63,000	118,000
Mathematics and statistics	77,000	57,000	80,000
Physical sciences	72,000	48,000	84,000
Psychology	67,000	47,000	69,000
Social sciences	68,000	46,000	70,000
Engineering	95,000	51,000	99,000
Health	80,000	45,000	83,000

SEH = science, engineering, and health.

Note(s)

Salaries are rounded to the nearest $1,000. Data include graduates from 19 months to 60 months prior to the survey reference date.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Survey of Doctorate Recipients (SDR) (2015), https://www.nsf.gov/statistics/srvydoctoratework/.

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Based on SDR data, among recent graduates, somewhat larger proportions of postdocs than non-postdocs have access to certain employer-provided benefits, such as health insurance (96% of postdocs and 92% of non-postdocs) and paid vacation, sick, or personal days (89% of postdocs and 85% of non-postdocs). However, a much smaller proportion of recent graduates in postdoc positions have access to employer-provided pensions or retirement plans (52% of postdocs and 82% of non-postdocs) or profit-sharing plans (8% of postdocs and 23% of non-postdocs). Information on the quality of these benefits—for example, the coverage and premium of health insurance plans, number of personal days offered by employers, and type of retirement benefits and profit-sharing plans—is not available.

Reasons for taking postdoc positions. The 2015 SDR asked individuals in postdoc positions to report their primary reason for accepting these appointments. Most responses were consistent with the traditional objective of a postdoc position as a type of advanced apprenticeship for career progression, such as “postdoc generally expected in field” (32%), “additional training in PhD field” (17%), “training in an area outside of PhD field” (15%), or “work with a specific person or place” (15%). A smaller proportion (14%) of those in postdoc appointments reported lack of other suitable employment as the primary reason for accepting these positions.

Characteristics of postdocs. According to the Survey of Graduate Students and Postdoctorates in Science and Engineering, women held 40% of the nearly 64,000 academic postdoc positions in 2015 in SEH fields.[9] Temporary visa holders accounted for 55% of the academic postdocs, and U.S. citizens and permanent residents accounted for the remaining 45%. Among postdocs in engineering, however, the proportion of women was lower (22%) and the proportion of temporary visa holders was higher (67%) than the overall SEH shares. Between 1979 and 2015, the number of academic postdocs increased more than threefold, driven primarily by temporary visa holders, who accounted for nearly two-thirds (64%) of the total increase. The majority of academic postdocs (62%) in 2015 were supported by research grants; the rest were supported by fellowships, traineeships, or other mechanisms.

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[1] The Business Cycle Dating Committee of the National Bureau of Economic Research is generally the source for determining the beginning and end of recessions or expansions in the U.S. economy; see https://www.nber.org/cycles/recessions.html for additional information. Data on unemployment is from the Bureau of Labor Statistics: https://data.bls.gov/timeseries/LNU04000000 (accessed 14 August 2017). The unemployment rate rose from 9.7% in June 2009, the official end of the recession, until it peaked at 10.6% in January of 2010. It did not fall below the June 2009 rate again until April 2010.

[2] The BLS civilian unemployment rate for persons 16 years and over, not seasonally adjusted, is available at https://data.bls.gov/timeseries/LNU04000000 (accessed 15 December 2016).

[3] The CPS is the source of the official U.S. unemployment rate.

[4] In this chapter, someone who is on tenure track but not yet tenured is referred to as “tenure-track” faculty.

[5] Although the formal job title is often *postdoc fellowship* or *research associate*, titles vary among organizations. This chapter generally uses the shorter, more commonly used, and best understood name, *postdoc*. A postdoc is generally considered a temporary position that individuals take primarily for additional training—a period of advanced professional apprenticeship—after completion of a doctorate.

[6] These estimates are new to this report and are based on the results of NSF’s ECDS. This pilot survey was developed to gather in-depth information about postdoc researchers and other early-career doctorate holders. The ECDS collects information related to educational achievement, professional activities, employer demographics, professional and personal life balance, mentoring, training and research opportunities, and career paths and plans for individuals who earned their doctorate in the past 10 years and are employed in an academic institution, a federally funded research and development center (FFRDC), or with one of the National Institutes of Health Intramural Research Programs (NIH IRP).

[7] While these surveys do not cover postdocs working in industry and government for the most part, they do collect data on postdocs in FFRDCs, which may be run by for-profit or nonprofit businesses, and the NIH IRP, which is in the government sector.

[8] These data are from the SED, which is administered to individuals receiving research doctoral degrees from all accredited U.S. institutions.

[9] The data tables for the 2015 Survey of Graduate Students and Postdoctorates in Science and Engineering are available at https://ncsesdata.nsf.gov/datatables/gradpostdoc/2015/ (accessed 2 June 2017).

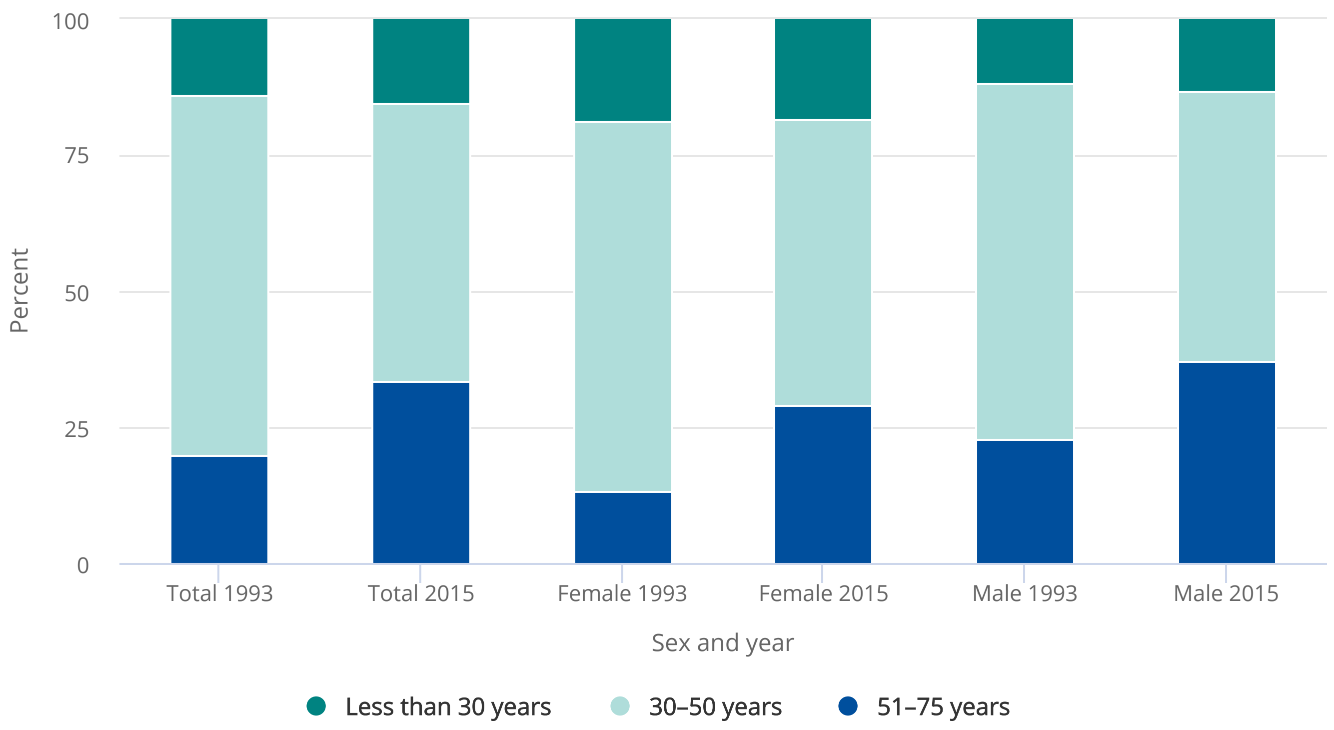
Age and Retirement of the S&E Workforce

The U.S. S&E workforce, reflecting overall population trends, is aging. This section focuses on indicators of the aging of the S&E workforce, including retirement patterns of S&E workers and workforce participation levels among older individuals. The age distribution and retirement patterns of S&E workers have important implications for the supply of S&E expertise in the economy, but the overall effect is uncertain. Over time, members of the S&E labor force may gain skills, experience, and judgment that translate into rising output and productivity. Consequently, the retirement of large numbers of experienced workers could mean the loss of valuable S&E expertise and knowledge. However, the retirement of older workers also makes room for newly trained S&E workers who may bring updated skills and new approaches to solving problems. (See Stephan and Levin [1992]; Jones, Reedy, and Weinberg [2014]; and Blau and Weinberg [2017] for in-depth discussions on age and scientific productivity.)

The aging of the S&E labor force is reflected in the median age, which has risen from 40 years in 1993 to 43 years in 2015. For proper context, the median age nationally for the U.S. population was 34 years in 1993 and 38 years in 2015.[1] Another indicator, the percentage of individuals in the S&E labor force between 51 and 75 years of age, has risen from about 20% in 1993 to 33% in 2015. Over that period, this proportion rose for both men and women, but the women in the labor force continue to be younger relative to their male counterparts (Figure 3-22). In 1993, the median ages were 38 years for women and 41 years for men, whereas in 2015 the median ages were 41 years for women and 45 years for men.

FIGURE 3-22

Age distribution of scientists and engineers in the labor force, by sex: 1993 and 2015



Note(s)

For 1993 data, scientists and engineers include those with one or more S&E degrees at the bachelor's level or higher or those who have only a non-S&E degree at the bachelor's level or higher and are employed in an S&E occupation. For 2013 data, scientists and engineers include those with one or more S&E or S&E-related degrees at the bachelor's level or higher or those who have only a non-S&E degree at the bachelor's level or higher and are employed in an S&E or S&E-related occupation. The Scientists and Engineers Statistical Data System (SESTAT) and the National Survey of College Graduates (NSCG) do not cover scientists and engineers over age 75.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, SESTAT (1993), https://www.nsf.gov/statistics/sestat/, and NSCG (2015), https://www.nsf.gov/statistics/srvygrads/.

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Age Differences among Occupations

College graduate workers in S&E occupations are younger than those in S&E-related or non-S&E occupations (Figure 3-23). In 2015, 28% of those in S&E occupations were between 51 and 75 years of age, compared to 33% of those in S&E-related occupations and 37% of those in non-S&E occupations. The median age of those employed in S&E occupations was 40 years, compared to 43 years among those employed in S&E-related occupations and 44 years for those employed in non-S&E

occupations. This may suggest, among other things, that as S&E workers age, they transition from S&E occupations to S&E-related (e.g., S&E managers) or non-S&E (e.g., non-S&E managers or other management-related) occupations.

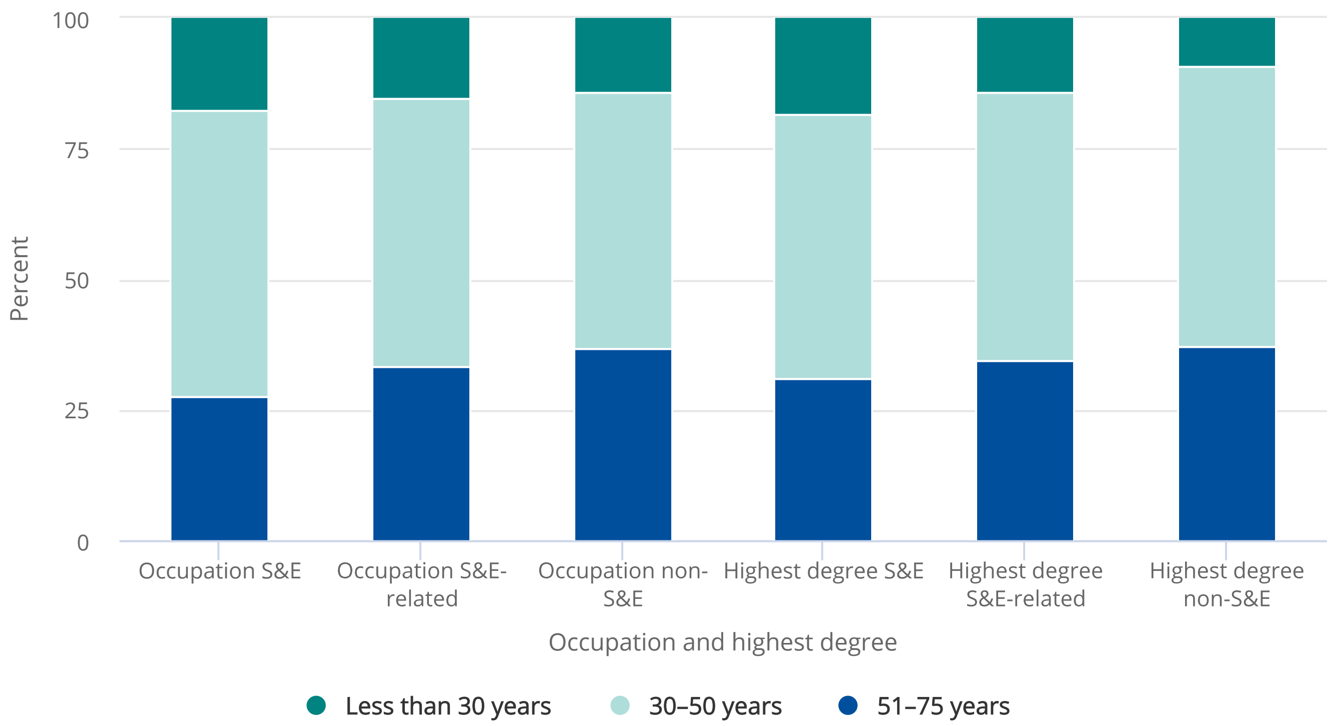
Age Differences among Degree Fields

Similar to the trend seen across broad occupational categories, S&E highest degree holders are generally younger than those holding highest degrees in S&E-related or non-S&E fields (📊 Figure 3-23). In 2015, a smaller proportion of S&E highest degree holders (31%) than S&E-related (35%) or non-S&E (37%) highest degree holders were between 51 and 75 years of age. In addition, degree holders in different S&E fields varied in their ages. S&E highest degree holders in physical sciences, particularly the men in this group, were older than those in other broad S&E fields (Appendix Table 3-11). S&E highest degree holders in computer and information sciences, a relatively new field with rapid growth, were relatively young: only about one-fourth were between 51 and 75 years of age.

Within broad degree areas, the age profile of different degree fields varies (Appendix Table 3-11). For example, within life sciences degree fields, between 23% and 29% of highest degree holders in biological sciences and environmental life sciences were between 51 and 75 years of age, compared with 50% of highest degree holders in agricultural and food sciences. In all broad S&E fields of highest degree except computer and mathematical sciences, women were younger than their male counterparts, reflecting the rising proportions of women in S&E (Appendix Table 3-11). Age differences among fields of study vary based on many different considerations, including the recent development of a field or a decline in new participants to a field as that field becomes less relevant to changes in the economy. Age variation may also indicate a situation in which experience is valued over new knowledge.

FIGURE 3-23

Age distribution of employed scientists and engineers, by broad occupational category and broad field of highest degree: 2015



Note(s)

Scientists and engineers include those with one or more S&E or S&E-related degrees at the bachelor's level or higher or those who have only a non-S&E degree at the bachelor's level or higher and are employed in an S&E or S&E-related occupation. The National Survey of College Graduates (NSCG) does not cover scientists and engineers over age 75. Percentages may not add to 100% because of rounding.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, NSCG (2015), https://www.nsf.gov/statistics/srvygrads/.

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Retirement

Trends in labor force participation among older individuals provide useful information about retirement patterns and how these patterns may have changed over time. Recent patterns of leaving the labor force and shifting to part-time work among older members of the workforce suggest that the labor force participation rate among scientists and engineers begins to decline sometime between the ages of 55 and 60 and is markedly reduced by the time workers reach their late 60s. One indication of the relationship between age and the level of labor force participation is illustrated by Figure 3-24, which shows the proportions of older scientists and engineers working full time. In 2015, at age 50, 78% of scientists and engineers worked full time (35 hours or more per week) in their principal job. Among individuals in their late 50s, this proportion dropped steeply. Among those in their late 60s, for example, less than one-third worked full time.

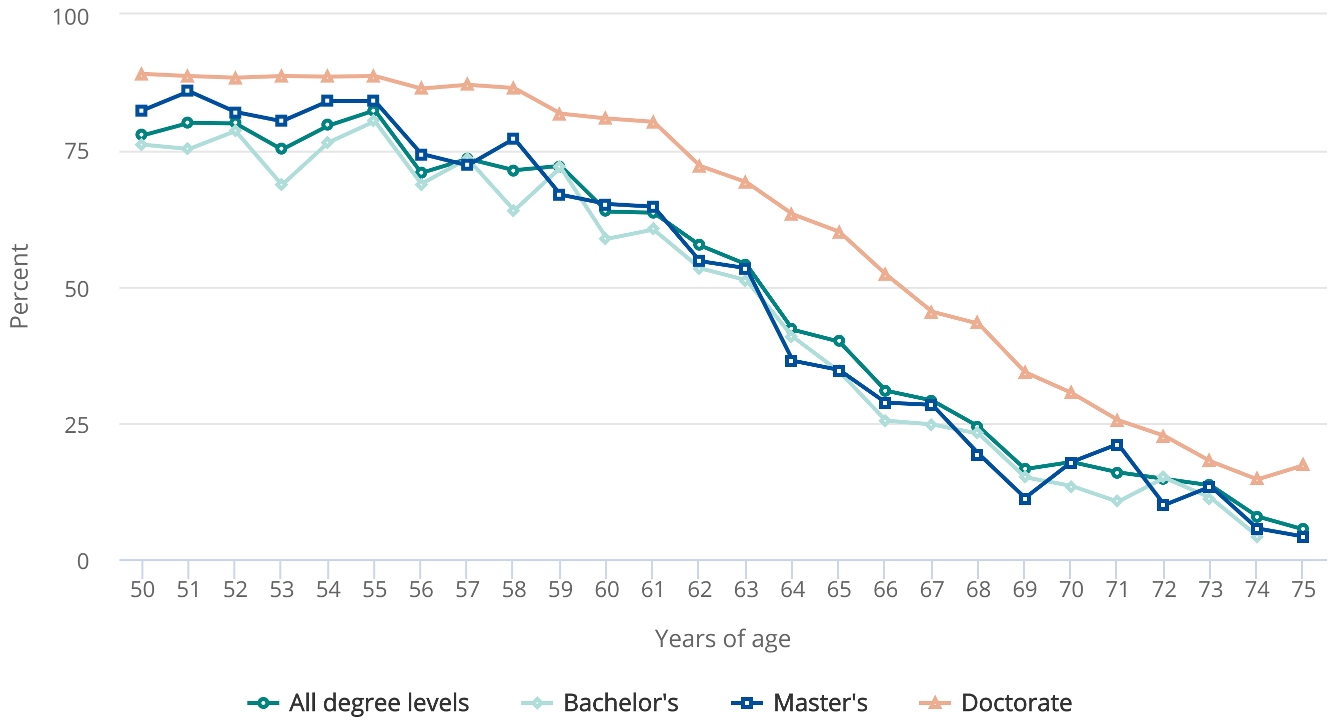
Between 1993 and 2015, increasing proportions of scientists and engineers in their 60s reported still being in the labor force. Whereas 69% of those aged 60–64 were in the labor force in 1993, by 2015 this had risen to 74%. For those between the ages of 65 and 69, the proportion rose from 39% in 1993 to 47% in 2015.[2] (See section Age Composition of the Academic Doctoral Workforce in Chapter 5 for a discussion of the age profile and retirement patterns of the academic S&E doctoral workforce.)

Reasons provided for labor force nonparticipation or part-time work status also shed light on the relationship between age and retirement (Figure 3-25 illustrates the relationship between age and labor force nonparticipation because of retirement). In 2015, about 3.3 million scientists and engineers reported that they were out of the labor force because of retirement. The vast majority (91%) of retired individuals were 60–75 years of age. Individuals with doctorates typically reported lower rates of retirement than those without doctorates.

Retirement does not always mean that workers permanently leave the labor force. After nominally retiring from their jobs, some workers continue to work part time, work in a different capacity, or decide to return to the labor market at a later time. About 1.8 million employed scientists and engineers in 2015 reported that they had previously retired from a job. A total of 793,000 scientists and engineers working part time in 2015 reported their reason for working part time as having “previously retired or semi-retired.” Individuals who chose to stay in or return to the labor market following an occurrence of retirement were younger (median age 62) than those who were out of the labor force following retirement (median age 67).

FIGURE 3-24

Older scientists and engineers who work full time, by age and highest degree level: 2015



Note(s)

Scientists and engineers include those with one or more S&E or S&E-related degrees at the bachelor's level or higher or those who have only a non-S&E degree at the bachelor's level or higher and are employed in an S&E or S&E-related occupation. All degree levels includes professional degrees not shown separately. Missing data have been suppressed for reasons of confidentiality and/or reliability.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Survey of College Graduates (NSCG) (2015), https://www.nsf.gov/statistics/srvygrads/, and the Survey of Doctorate Recipients (SDR) (2015), https://www.nsf.gov/statistics/srvydoctoratework/.

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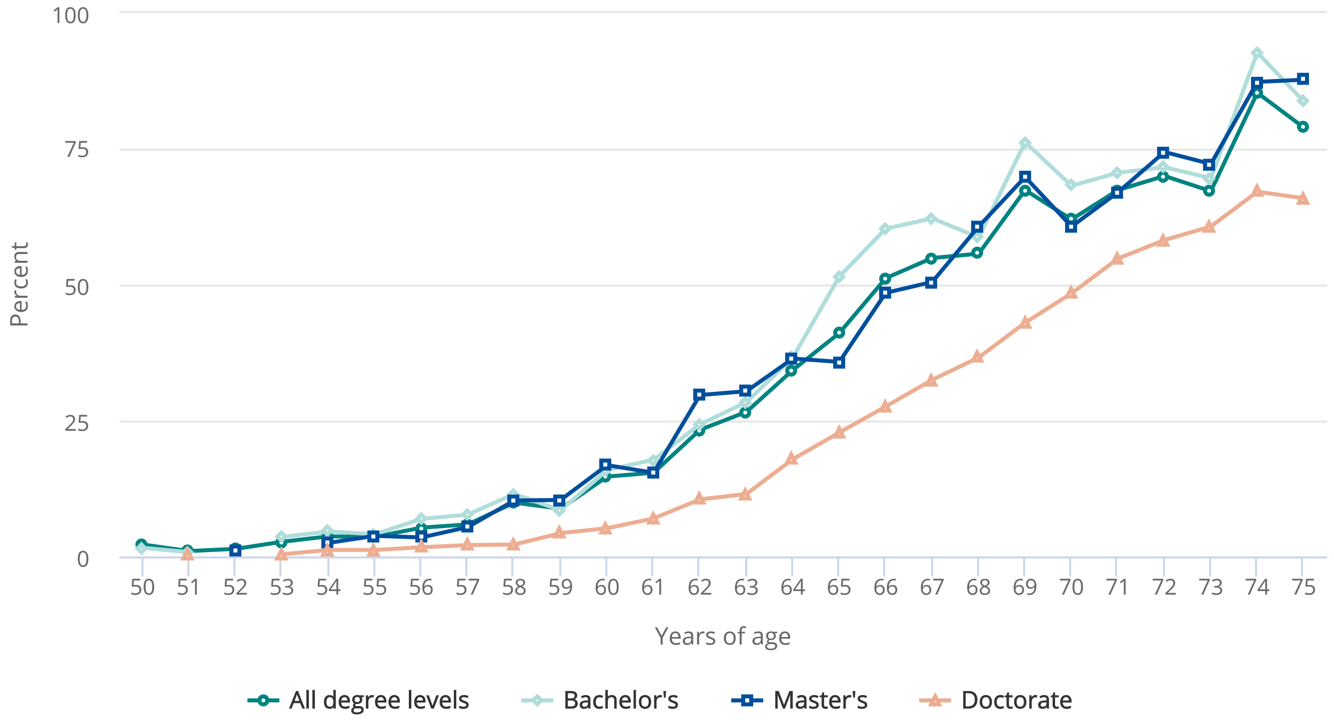
FIGURE 3-25

Older scientists and engineers who report not working because of retirement, by age and highest degree level: 2015



Note(s)

Scientists and engineers include those with one or more S&E or S&E-related degrees at the bachelor's level or higher or those who have only a non-S&E degree at the bachelor's level or higher and are employed in an S&E or S&E-related occupation. All degree levels includes professional degrees not shown separately. Missing data have been suppressed for reasons of confidentiality and/or reliability.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Survey of College Graduates (NSCG) (2015), https://www.nsf.gov/statistics/srvygrads/, and the Survey of Doctorate Recipients (SDR) (2015), https://www.nsf.gov/statistics/srvydoctoratework/.

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[1] The 2015 data on median age for the U.S. population are from the U.S. Census Bureau's American FactFinder and are available at https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_15_5YR_DP05&src=pt. The 1993 data are available at https://www.census.gov/population/estimates/nation/intfile3-1.txt (accessed 16 October 2017).

[2] In 1994, the Age Discrimination in Employment Act of 1967 became fully applicable to universities and colleges, prohibiting the forced retirement of faculty at any age.

Women and Minorities in the S&E Workforce

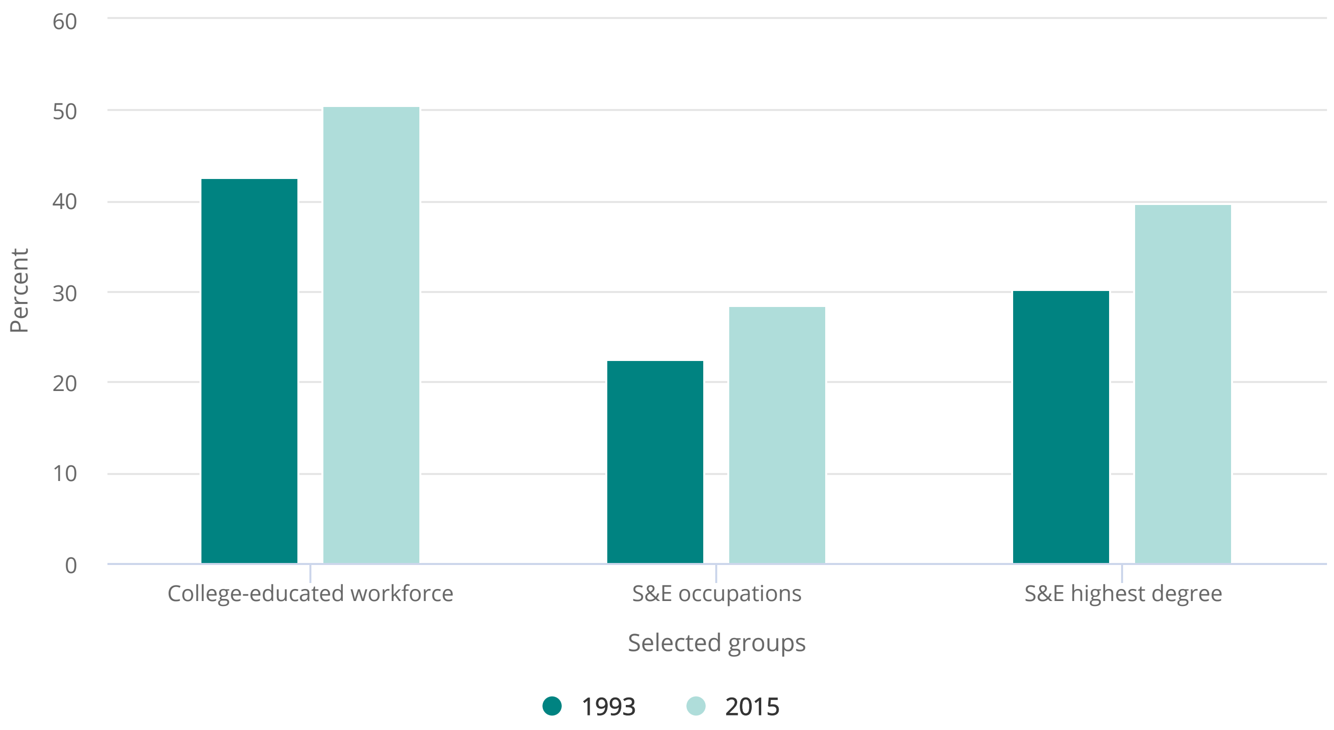
As researchers and policymakers increasingly emphasize the need for expanding S&E capabilities in the United States, demographic groups with lower rates of S&E participation represent an underutilized source of human capital for S&E work. The lower participation signals a lack of diversity in the workplace, negatively impacting productivity and innovation (see Hewlett, Marshall, and Sherbin [2013] and Ellison and Mullin [2014] for discussions on the impact of diversity on workplace productivity and innovation). Historically, in the United States, S&E fields have had particularly low representation of women and members of several racial and ethnic minority groups (i.e., blacks, Hispanics, American Indians or Alaska Natives), both relative to the concentrations of these groups in other occupational or degree areas and relative to their overall representation in the general population. More recently, however, women and racial and ethnic minorities increasingly have been choosing a wider range of degrees and occupations. This section presents data on S&E participation among women and among racial and ethnic minorities. It also presents data on earnings differentials by sex and by race and ethnicity.

Women in the S&E Workforce

Historically, men have outnumbered women by wide margins in both S&E employment and S&E training. Although the number of women in S&E occupations or with S&E degrees has doubled over the past two decades, the disparity has narrowed only modestly. This imbalance is still particularly pronounced in S&E occupations. In 2015, women constituted only 28% of workers in these occupations, although they accounted for half of the college-educated workforce overall. Among S&E degree holders, the disparity was smaller but nonetheless significant, with women representing 40% of employed individuals with a highest degree in S&E (📊 Figure 3-26).

FIGURE 3-26

Women in the workforce and in S&E: 1993 and 2015



Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Scientists and Engineers Statistical Data System (SESTAT), https://www.nsf.gov/statistics/sestat/, and the National Survey of College Graduates (NSCG) (1993, 2015), https://www.nsf.gov/statistics/srvygrads/.

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Women in S&E Occupations

Although women represented only 28% of individuals in S&E occupations in 2015, women's participation varies widely across S&E occupational fields (Figure 3-27; Appendix Table 3-12). The percentage of female S&E workers continues to be lowest in engineering, where women constituted 15% of the workforce in 2015. Among engineering occupations with large numbers of workers, women accounted for only 9% of the workforce of mechanical engineers and about 10% to 13% of the workforce of electrical and computer hardware engineers and of aerospace, aeronautical, and astronautical engineers. However, among civil engineers, women make up about one-fifth of the workers (Appendix Table 3-12).

Other disproportionately male S&E occupations include physical scientists (28% women) and computer and mathematical scientists (26% women). Within computer and mathematical sciences occupations, the largest component, computer and information scientists, has a smaller proportion of women (24%) compared with the mathematical scientists component, which is closer to parity (43% women).

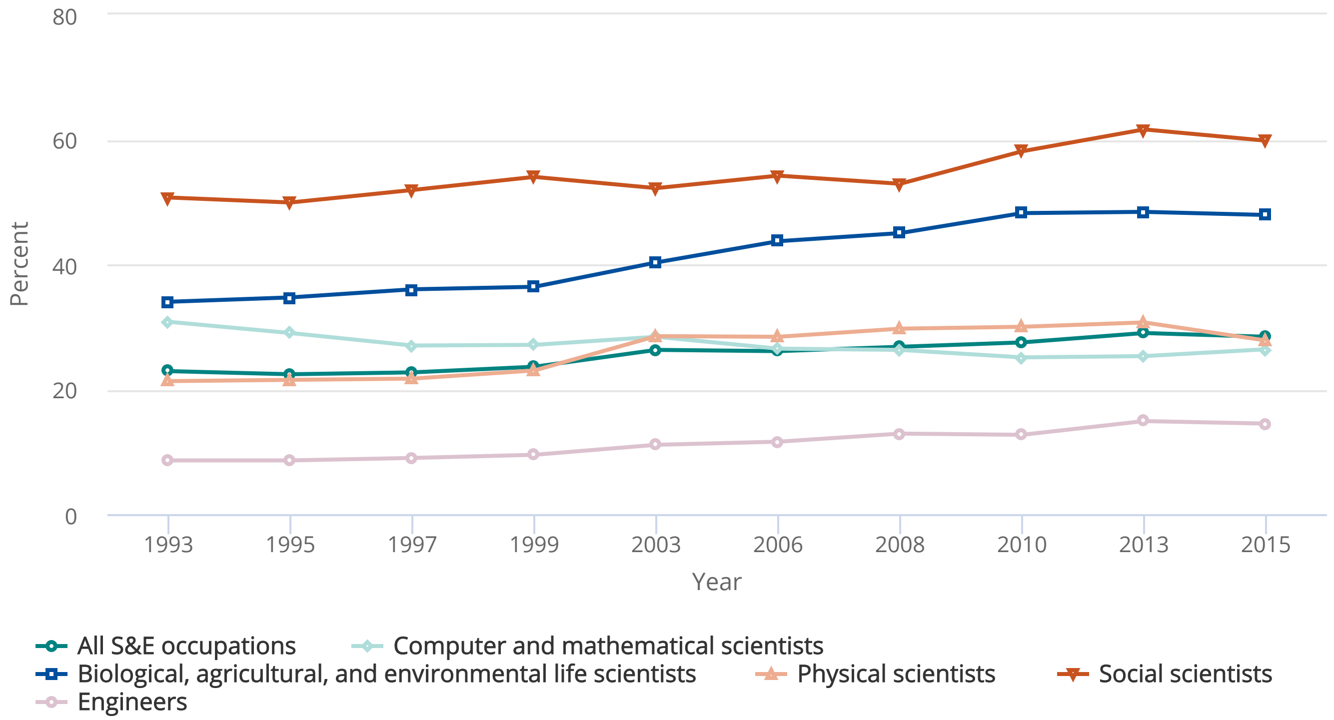
In 2015, sex parity in S&E occupations was close among life scientists (48% women). The largest component of life sciences, biological and medical scientists, had reached gender parity (53% women). The field of social sciences was majority female (60%). Occupations within social sciences, however, varied widely: women accounted for only 38% of economists but for 73% of psychologists. Psychologists, estimated at about 213,000 total workers (Appendix Table 3-12), are a large S&E occupation with substantially more women than men.

In contrast to jobs in S&E occupations, a majority of jobs in S&E-related occupations (58%) are held by women (Appendix Table 3-12). The largest component, health-related occupations, has a large share of women (70%) whose jobs are primarily as nurse practitioners, pharmacists, registered nurses, dietitians, therapists, physician assistants, and health technologists and technicians; women represented the majority of workers in these particular health occupations. In contrast, among health occupations such as diagnosing and treating practitioners, women accounted for a much smaller proportion (42%).

Since the early 1990s, the number of women working in each broad S&E occupational category has risen significantly (Figure 3-27). The rate of growth has been strong among life scientists, computer and mathematical scientists, and social scientists. These three broad S&E fields together employed 81% of women in S&E occupations in 2015, compared with 63% of men in S&E occupations (Appendix Table 3-12). Between 1993 and 2015, the number of women nearly tripled among life scientists (an increase of 175%) and more than doubled among social scientists (an increase of 112%). The number of men also grew, but the rate of growth for women was greater than that for men, resulting in an increase in the proportion of female life scientists and female social scientists.

FIGURE 3-27

Women in S&E occupations: 1993–2015



Note(s)

National estimates were not available from the Scientists and Engineers Statistical Data System (SESTAT) in 2001.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, SESTAT (1993–2013), https://www.nsf.gov/statistics/sestat/, and the National Survey of College Graduates (NSCG) (2015), https://www.nsf.gov/statistics/srvygrads/.

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During the same period, the number of women in computer and mathematical sciences occupations also nearly tripled (an increase of 173%). However, this new, rapidly growing and changing field attracted relatively more men than women (male participation grew 239%). The result has been an overall decline in the proportion of women, from 31% to 26%. These trends make the gender disparity among computer and mathematical scientists second only to the gender disparity among engineers. However, the declining proportion of women in computer and mathematical sciences occupations does not extend to doctorate-level workers: Among those with a doctorate, the proportion of women increased, from 16% in 1993 to 26% in 2015.

During the past two decades, the proportion of women also increased among workers in engineering (from 9% to 15%) and in physical sciences (from 21% to 28%). In these two occupational categories, this increase was led by an expansion of women's numbers in the workforce (by 108% in engineering and 53% in physical sciences), while men's numbers barely changed between 1993 and 2015.

Women among S&E Highest Degree Holders

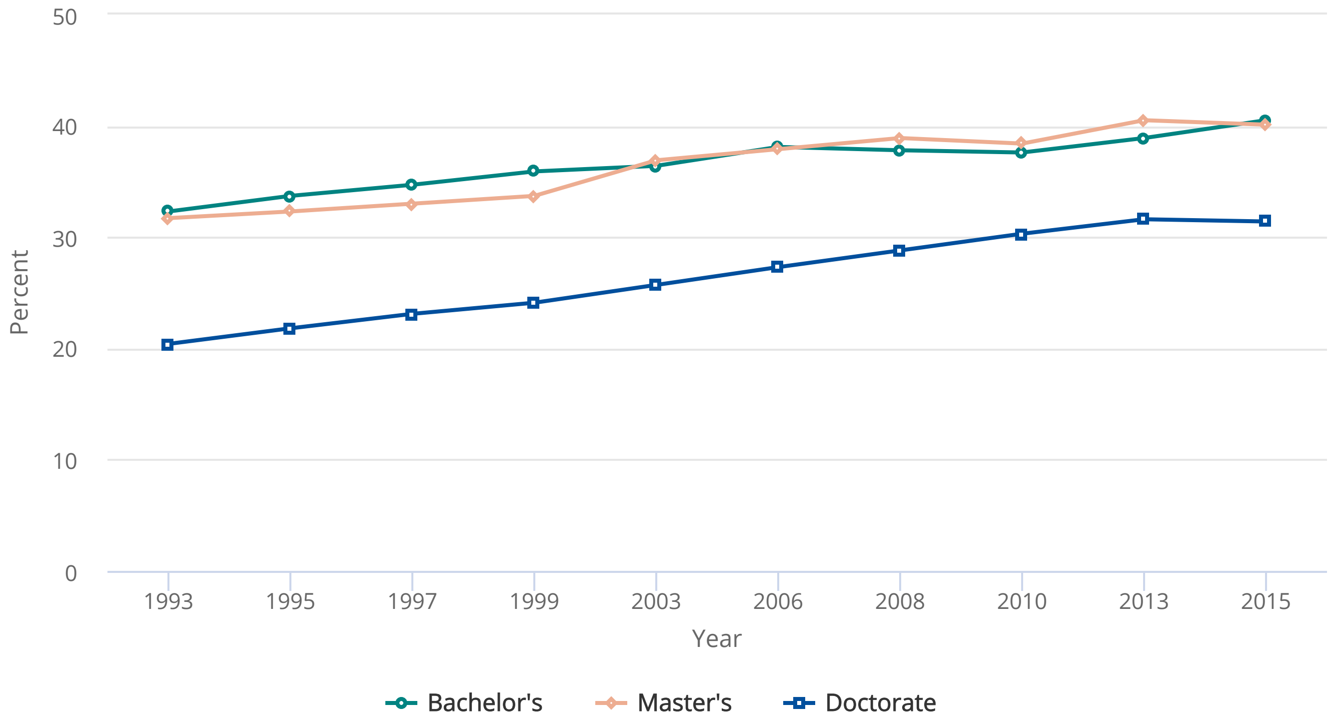
The sex disparity among employed S&E highest degree holders is less than the disparity among those in S&E occupations. In 2015, among individuals with a highest degree in an S&E field, women constituted 40% of those who were employed, up from 30% in 1993 (Figure 3-26). The pattern of variation in the proportion of men and women among degree fields echoes the pattern of variation among occupations associated with those fields (Appendix Table 3-13). In 2015, 57% of S&E highest degree holders in social sciences fields were women, as were 51% of those with a highest degree in the biological and related sciences. Men outnumbered women among computer and mathematical sciences highest degree holders (28% women) and among physical sciences highest degree holders (34% women). Disparities, however, were greatest among those with a highest degree in engineering (15% women).

In all broad S&E fields except computer and mathematical sciences, the proportion of women in the workforce with associated highest degrees has been increasing since 1993. In computer and mathematical sciences, this proportion has declined as the number of women with a highest degree in the field has risen, but women's numbers have increased less than those of men in this new and rapidly growing field.

Sex differences are not limited to the field of degree but also extend to the level of S&E degree. Overall, men outnumber women among S&E highest degree holders at the bachelor's, master's, and doctoral degree levels. The sex disparity is more severe among S&E doctorate holders than among S&E bachelor's or master's degree holders. For example, in 2015, women accounted for 41% and 40% of those whose highest degree in S&E was at the bachelor's or master's degree level, respectively, but for 31% of those whose highest degree in S&E was at the doctoral level. Engineering was an exception: in this field, women represented similar proportions of highest degree holders at the bachelor's (15%) and doctorate degree levels (13%). However, for S&E fields overall at all three degree levels, the proportion of women has risen in the past two decades (Figure 3-28).

FIGURE 3-28

Employed women with highest degree in S&E, by degree level: 1993–2015



Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Scientists and Engineers Statistical Data System (SESTAT) (1993–2013), https://www.nsf.gov/statistics/sestat/, and the National Survey of College Graduates (NSCG) (2015), https://www.nsf.gov/statistics/srvygrads/.

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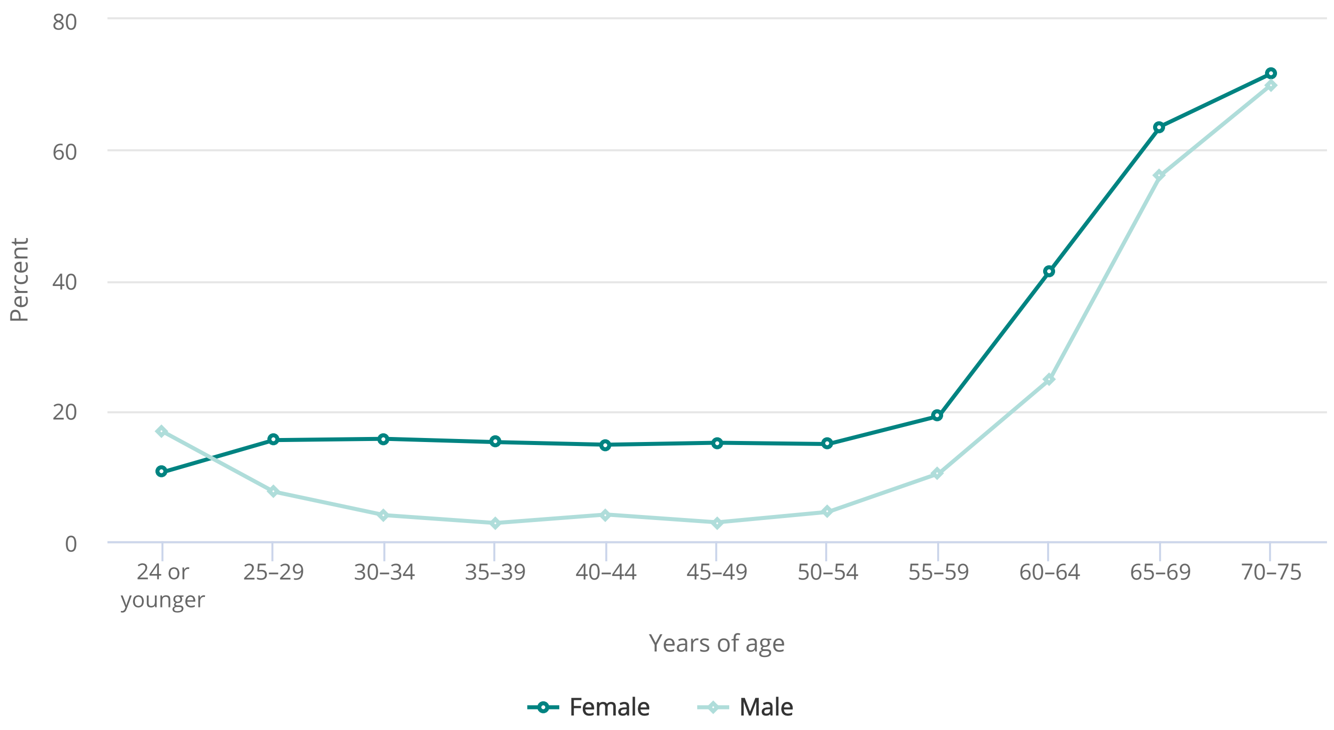
Working men and women with S&E highest degrees also differ in the extent to which they are employed in the same field as their S&E highest degree. This disparity is largely the result of women having a high concentration in the two degree areas —social sciences and life sciences—where degree holders most often work in an occupation outside of S&E. In 2015, these two broad fields accounted for nearly three-fourths (74%) of all employed women with S&E highest degrees, compared with 40% of all employed men with S&E highest degrees (Appendix Table 3-13).

Across all S&E degree areas, 18% of women with an S&E highest degree are employed in the S&E field in which they earned their highest degree, compared with 33% of men (Appendix Table 3-14). However, the pattern varies by degree fields. Among life sciences and engineering degree holders, similar proportions of men and women are employed in the broad S&E field in which they earned their degree. Computer and mathematical sciences fields represent an exception in which a larger proportion of men (59%) than women (43%) work in an occupation that matches their broad degree field and a larger proportion of women (37%) than men (25%) work in non-S&E occupations. The majority of social sciences degree holders work in non-S&E occupations, and this pattern is observed among both male (78%) and female (81%) degree holders.

Men and women with a highest degree in an S&E field also differ in their labor force nonparticipation rates. Compared with men, women are more likely to be out of the labor force (22% versus 16% for men). The difference in nonparticipation was particularly pronounced between the ages of 30 and 65 (Figure 3-29). In 2015, 19% of the women in this age group with an S&E highest degree were out of the labor force, compared with 8% of the men. Many women in this group identified family reasons as an important factor: 44% of women reported that family was a factor for their labor force nonparticipation, compared with 12% of men. Within this age range, women were also much more likely than men to report that they did not need to work or did not want to work (29% of women versus 17% of men). Men, on the other hand, were much more likely than women to cite retirement as a reason for not working (24% of women versus 50% of men).

FIGURE 3-29

Highest degree holders in S&E not in the labor force, by sex and age: 2015



Note(s)

Not in the labor force includes those neither working nor looking for work in the 4 weeks prior to February 2015.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Scientists and Engineers Statistical Data System (SESTAT) (2015), https://www.nsf.gov/statistics/sestat/.

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Minorities in the S&E Workforce

The participation of underrepresented racial and ethnic minorities in the S&E workforce has been a concern of policymakers who are interested in the development and employment of diverse human capital to maintain the United States' global competitiveness in S&E. This section addresses the level of diversity in S&E by race and Hispanic ethnicity.[1] Like the preceding section, this section draws on data from NSF's surveys to report on levels of S&E participation, first across occupations and then across the overall workforce with S&E degrees.

Whether defined by occupation, S&E degree, or a combination of the two, the majority of scientists and engineers in the United States are non-Hispanic whites. The next largest group of scientists and engineers are Asians. Several racial and ethnic minority groups, including blacks, Hispanics, and American Indians or Alaska Natives, have low levels of participation in S&E fields both compared with other groups and compared with their proportion in the population (▦Table 3-19).

Race and Ethnicity Trends in S&E Occupations

In 2015, among the 6.4 million workers employed in S&E occupations, 67% were white, which is close to the proportion (66%) in the U.S. population age 21 and older (▦Table 3-19). However, S&E participation by whites varied across the broad S&E occupational categories, from 62% of computer and mathematical scientists to 70% or more among the remaining broad S&E occupational fields of biological and life scientists, physical and related scientists, social scientists, and engineers (Appendix Table 3-15). The concentration of whites in some occupations was more pronounced: they accounted for at least 90% of workers among forestry and conservation scientists and geologists and earth scientists.

Asians, with 1.3 million workers in S&E occupations, accounted for 21% of S&E employment, much higher than their share of the U.S. population age 21 and older (6%). Asians had a large presence in computer and engineering occupations, constituting 38% of computer software engineers, 34% of software developers, 34% of computer hardware engineers, 36% of computer and information research scientists, and 30% of postsecondary teachers in engineering (Appendix Table 3-15). On the contrary, the proportion of Asians in social sciences occupations was much lower than their proportions in other S&E fields.

Overall, Hispanics accounted for 6% of employment in S&E occupations, which is lower than their share of the U.S. population age 21 and older (15%) (▦Table 3-19). Hispanics had a particularly large presence among psychologists (13%) and economists (13%); aerospace, aeronautical, or astronautical engineers (12%); and industrial engineers (9%). Blacks accounted for 5% of S&E employment, which is lower than their share of the U.S. population age 21 and older (12%). Blacks had relatively high participation rates among computer systems analysts (8%), computer support specialists (10%), information security analysts (13%), psychologists (9%), and industrial engineers (9%).

TABLE 3-19

Racial and ethnic distribution of U.S. residents, and of employed individuals in S&E occupations, with S&E degrees, and with college degrees: 2015

(Percent)

Race and ethnicity	S&E occupations	S&E highest degree holders	College degree holders	U.S. residential population[a]
Total (number)	6,407,000	13,497,000	45,941,000	231,875,000
American Indian or Alaska Native	0.2	0.3	0.3	0.6
Asian	20.6	15.1	8.7	5.5
Black	4.8	6.4	7.5	11.8
Hispanic	6.0	8.4	8.2	14.9
Native Hawaiian or Other Pacific Islander	0.2	0.3	0.4	0.1
White	66.6	67.6	72.9	65.6
More than one race	1.6	1.9	2.0	1.5

[a] Age 21 and older.

Note(s)

Hispanic may be any race; American Indian or Alaska Native, Asian, black or African American, Native Hawaiian or Other Pacific Islander, white, and more than one race refer to individuals who are not of Hispanic origin.

Source(s)

Census Bureau, American Community Survey (ACS) (2015); National Science Foundation, National Center for Science and Engineering Statistics, National Survey of College Graduates (NSCG) (2015), https://www.nsf.gov/statistics/srvygrads/.

Science and Engineering Indicators 2018

Over the past two decades, the U.S. workforce in S&E occupations has become more diverse, with increasing proportions of Asians, blacks, and Hispanics and a decreasing proportion of whites (Table 3-20). In 1993, 84% of workers in S&E occupations reported their race as white. By 2015, this proportion had declined to 67%. Most of the decline in the proportion of whites during this period was offset by an increase in the proportion of Asians and, to a lesser degree, by increases in the proportion of other groups, particularly Hispanics.

Some of the changes by race over time may reflect changes in the way that NSF and other federal agencies collect information on this topic as well as changes in racial composition of the general population over time. After 2000, respondents to NSF surveys were able to report more than one race. Some of those who self-reported as white in the 1990s may have instead reported a multiracial identity after 2000 once they were given this option, which would decrease the estimated numbers of whites. However, because less than 2% of S&E workers reported a multiracial identity in years when that option was available, it is unlikely that this change contributed much to the decline in the proportion of whites between 1993 and 2015.

TABLE 3-20

Distribution of workers in S&E occupations, by race and ethnicity: Selected years, 1993–2015

(Percent)

Race and ethnicity	1993	1995	1997	1999	2003	2006	2008	2010	2013	2015
American Indian or Alaska Native	0.2	0.3	0.3	0.3	0.3	0.4	0.3	0.2	0.2	0.2
Asian	9.1	9.6	10.4	11.0	14.2	16.1	16.9	18.5	17.4	20.6
Black	3.6	3.4	3.4	3.4	4.3	3.9	3.9	4.6	4.8	4.8
Hispanic	2.9	2.8	3.1	3.4	4.4	4.6	4.9	5.2	6.1	6.0
Native Hawaiian or Other Pacific Islander	NA	NA	NA	NA	0.3	0.5	0.4	0.2	0.2	0.2
White	84.1	83.9	82.9	81.8	75.2	73.2	71.8	69.9	69.9	66.6
More than one race	NA	NA	NA	NA	1.4	1.4	1.7	1.4	1.5	1.6

NA = not available.

Note(s)

Hispanic may be any race; American Indian or Alaska Native, Asian, black or African American, Native Hawaiian or Other Pacific Islander, white, and more than one race refer to individuals who are not of Hispanic origin. Before 2003, respondents could not classify themselves in more than one racial and ethnic category, and Asian included Native Hawaiian and Other Pacific Islander. Percentages may not add to 100% because of rounding.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Scientists and Engineers Statistical Data System (SESTAT) (1993–2013), https://www.nsf.gov/statistics/sestat/, and the National Survey of College Graduates (NSCG) (2015), https://www.nsf.gov/statistics/srvygrads/.

Science and Engineering Indicators 2018

Racial and Ethnic Differences among S&E Degree Holders

Among those in the workforce whose highest degree is in S&E, the shares of racial and ethnic groups vary similarly across degree fields, as they do in occupations (Table 3-21; Appendix Table 3-16). Compared to most other broad S&E fields, Asians have higher participation rates among those with degrees in engineering and in computer and mathematical sciences; blacks have higher participation rates among those with degrees in computer and mathematical sciences and in social sciences; Hispanics have slightly lower participation rates among those with degrees in computer and mathematical sciences and in physical sciences. Whites represent smaller segments of degree holders in engineering and computer and mathematical sciences than in life, physical, and social sciences.

TABLE 3-21

Racial and ethnic distribution of employed individuals with S&E highest degree, by field of highest degree: 2015

(Percent)

Race and ethnicity	All S&E fields	Biological, agricultural, and environmental life sciences	Computer and mathematical sciences	Physical sciences	Social sciences	Engineering
Employed with highest degree in S&E (number)	13,497,000	2,116,000	2,346,000	789,000	5,056,000	3,190,000
American Indian or Alaska Native	0.3	0.3	0.1	s	0.4	0.3
Asian	15.1	13.3	23.1	17.5	7.1	22.5
Black	6.4	5.4	7.3	3.2	8.6	3.8
Hispanic	8.4	8.2	5.8	5.4	10.0	8.7
Native Hawaiian or Other Pacific Islander	0.3	0.2	0.3	s	0.5	0.2
White	67.6	71.1	61.6	72.4	70.9	63.1
More than one race	1.9	1.6	1.8	1.0	2.5	1.4

s = suppressed for reasons of confidentiality and/or reliability.

Note(s)

Hispanic may be any race; American Indian or Alaska Native, Asian, black or African American, Native Hawaiian or Other Pacific Islander, white, and more than one race refer to individuals who are not of Hispanic origin. Percentages may not add to 100% because of rounding.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Survey of College Graduates (NSCG) (2015), https://www.nsf.gov/statistics/srvygrads/.

Science and Engineering Indicators 2018

The demographic groups also differ in the level of their S&E highest degree (Table 3-22), with Asians accounting for larger proportions of those whose highest degree is at the master's or doctoral level, relative to their counterparts with a highest degree at the bachelor's level. Conversely, blacks, Hispanics, and whites all represent larger proportions of those whose highest degree is at the bachelor's degree level, relative to those with a doctorate as their highest degree.

Asian S&E highest degree holders are more likely than those in other racial and ethnic groups to work in S&E occupations and to work in the area in which they earned their degree. Among black, Hispanic, and white S&E degree holders, between 20% and 26% work in their same broad field, compared to 37% among Asian S&E degree holders (Appendix Table 3-14).

TABLE 3-22

Racial and ethnic distribution of employed individuals with S&E highest degree, by level of highest degree: 2015

(Percent)

Race and ethnicity	Bachelor's	Master's	Doctorate
Employed with highest degree in S&E (number)	9,539,000	2,934,000	992,000
American Indian or Alaska Native	0.3	0.2	s
Asian	11.2	25.0	23.2
Black	7.1	5.4	3.4
Hispanic	9.1	7.3	4.6
Native Hawaiian or Other Pacific Islander	0.4	0.1	s
White	69.9	60.4	66.9
More than one race	2.0	1.6	1.3

s = suppressed for reasons of confidentiality and/or reliability.

Note(s)

Hispanic may be any race; American Indian or Alaska Native, Asian, black or African American, Native Hawaiian or Other Pacific Islander, white, and more than one race refer to individuals who are not of Hispanic origin.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Survey of College Graduates (NSCG) (2015), https://www.nsf.gov/statistics/srvygrads/.

Science and Engineering Indicators 2018

Women in S&E by Race and Ethnicity

The rise in female participation in S&E over the past two decades was the result of increasing participation by all race and ethnic groups, although the growth among Asian and Hispanic women was particularly strong. Among workers in S&E occupations, the number of women who identified themselves as Asian or Hispanic increased sixfold between 1995 and 2015. As a result, both the Asian share and the Hispanic share of female workers in S&E occupations rose during this period (Table 3-23). The number of women employed in S&E occupations who reported themselves as black more than doubled (rising by 159%) between 1995 and 2015. In comparison, although the number of female workers who identified themselves as being white and not of Hispanic origin rose substantially (97%), their participation did not grow as steeply as members of other race and ethnic groups, resulting in an overall decline in the share of white female S&E workers over time (Table 3-23). A broadly similar pattern is observed among female S&E highest degree holders.

TABLE 3-23

Racial and ethnic distribution of employed women in S&E occupations and with S&E highest degrees: 1995 and 2015

(Percent)

Race and ethnicity	Women in S&E occupations		Women with S&E highest degrees	
	1995	2015	1995	2015
Total (number)	714,000	1,818,000	2,391,000	5,376,000
American Indian or Alaska Native	0.3	0.1	0.3	0.2
Asian	9.8	22.9	7.2	14.1
Black	5.6	5.7	7.9	8.2
Hispanic	2.9	6.4	3.8	10.2
Native Hawaiian or Other Pacific Islander	NA	0.1	NA	0.2
White	81.3	62.9	80.8	64.9
More than one race	NA	1.7	NA	2.2

NA = not available.

Note(s)

Hispanic may be any race; American Indian or Alaska Native, Asian, black or African American, Native Hawaiian or Other Pacific Islander, white, and more than one race refer to individuals who are not of Hispanic origin. In 1993, respondents could not classify themselves in more than one racial and ethnic category, and Asian included Native Hawaiian and Other Pacific Islander. Percentages may not add to 100% because of rounding.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Scientists and Engineers Statistical Data System (SESTAT) (1995), https://www.nsf.gov/statistics/sestat/, and the National Survey of College Graduates (NSCG) (2015), https://www.nsf.gov/statistics/srvygrads/.

Science and Engineering Indicators 2018

Salary Differences for Women and Racial and Ethnic Minorities

Women and racial and ethnic minority groups generally receive less pay than their male and white counterparts (Table 3-24). However, salary differences between men and women were somewhat larger than salary differences among racial and ethnic groups (Table 3-24; Appendix Table 3-17 and Appendix Table 3-18).

TABLE 3-24

Median annual salary among S&E highest degree holders working full time, by sex, race, and ethnicity: 1995, 2003, and 2015

(Dollars)

Characteristic	1995	2003	2015
All	44,000	60,000	75,000
Sex			
Female	34,000	45,000	57,000
Male	49,000	68,000	86,000
Race and ethnicity			
American Indian or Alaska Native	s	48,000	62,000
Asian	45,000	64,000	85,000
Black	35,000	48,000	55,000
Hispanic	38,000	50,000	59,000
Native Hawaiian or Other Pacific Islander	NA	56,000	74,000
White	45,000	60,000	78,000
More than one race	NA	50,000	61,000

NA = not available; s = suppressed for reasons of confidentiality and/or reliability.

Note(s)

Salaries are rounded to the nearest $1,000. Data for 1995 include some individuals with multiple races in each category. Hispanic may be any race; American Indian or Alaska Native, Asian, black or African American, Native Hawaiian or Other Pacific Islander, white, and more than one race refer to individuals who are not of Hispanic origin.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Scientists and Engineers Statistical Data System (SESTAT) (1995, 2003), https://www.nsf.gov/statistics/sestat/, and the National Survey of College Graduates (NSCG) (2015), https://www.nsf.gov/statistics/srvygrads/.

Science and Engineering Indicators 2018

Effects of Education, Employment, and Experience on Salary Differences

Salaries differ across degree field, occupational field and sector, and experience. Such differences in degree and occupational fields account for a portion of the salary differences by sex and by race and ethnicity. Median salaries in 2015 were generally higher among full-time workers with a highest degree in engineering ($92,000), computer and mathematical sciences ($97,000), or physical sciences ($78,000) than for those with a highest degree in life sciences ($62,000) or social sciences ($69,000). Degree areas with lower salaries generally have higher concentrations of women and of racial and ethnic minorities. Disproportionately larger shares of degree holders in life sciences, and particularly in social sciences, compared with other S&E degree fields, work in occupations not categorized as S&E, and the salaries for these occupations are generally lower than for S&E occupations (Appendix Table 3-17).

Salaries also differ across employment sectors. Academic and nonprofit employers typically pay less for similar skills than employers in the private sector, and government compensation generally falls somewhere between these two groups. These differences are important for understanding salary variations by sex and by race and ethnicity because men, Asians, and whites are more highly concentrated in the private, for-profit sector.

Salaries also vary by indicators of experience, such as age and years since completing one's degree. Because of the rapid increase in female participation in S&E fields in recent years, women with S&E degrees who are employed full time generally have fewer years of labor market experience than their male counterparts: the median number of years since highest degree is 14 years for women versus 17 years for men; the median age is 39 years for women versus 43 years for men. Whites with S&E degrees who are employed full time also generally have more years of labor market experience than other racial and ethnic groups: the median number of years since highest degree is 18 years for whites, 14 years for Asians, 11 years for Hispanics, and 12 years for blacks.

Differences in average age, work experience, academic training, sector and occupation of employment, and other characteristics can make direct comparison of salary statistics misleading. Statistical models can estimate the size of the salary difference between men and women, or the salary differences between racial and ethnic groups, when various salary-related factors are taken into account. Estimates of these differences vary somewhat depending on the assumptions that underlie the statistical model used. The analyses presented in this section show that statistical models used to control for effects of education, experience, and other factors on salaries tend to reduce, but not fully eliminate, the disparities. The remainder of this section presents estimated salary differences between men and women among individuals who are otherwise similar in age, work experience, field of highest degree, occupational field and sector, number of children, and other relevant characteristics that are likely to influence salaries. Data related to salary differences between minorities (American Indians or Alaska Natives, blacks, Hispanics, Native Hawaiians or Other Pacific Islanders, and those reporting more than one race) and Asians and whites are also included.

Accounting only for level of degree, women working full time whose highest S&E degree is at the bachelor's level earned 30% less than men (Figure 3-30).[2] The salary difference is smaller but substantial at both the master's level (28%) and the doctoral level (21%). The salary differences for non-Asian minorities relative to whites and Asians are narrower (Figure 3-31). On average, minority salary levels are 24% lower than those of whites and Asians at the bachelor's level, 18% lower at the master's level, and 14% lower at the doctoral level.

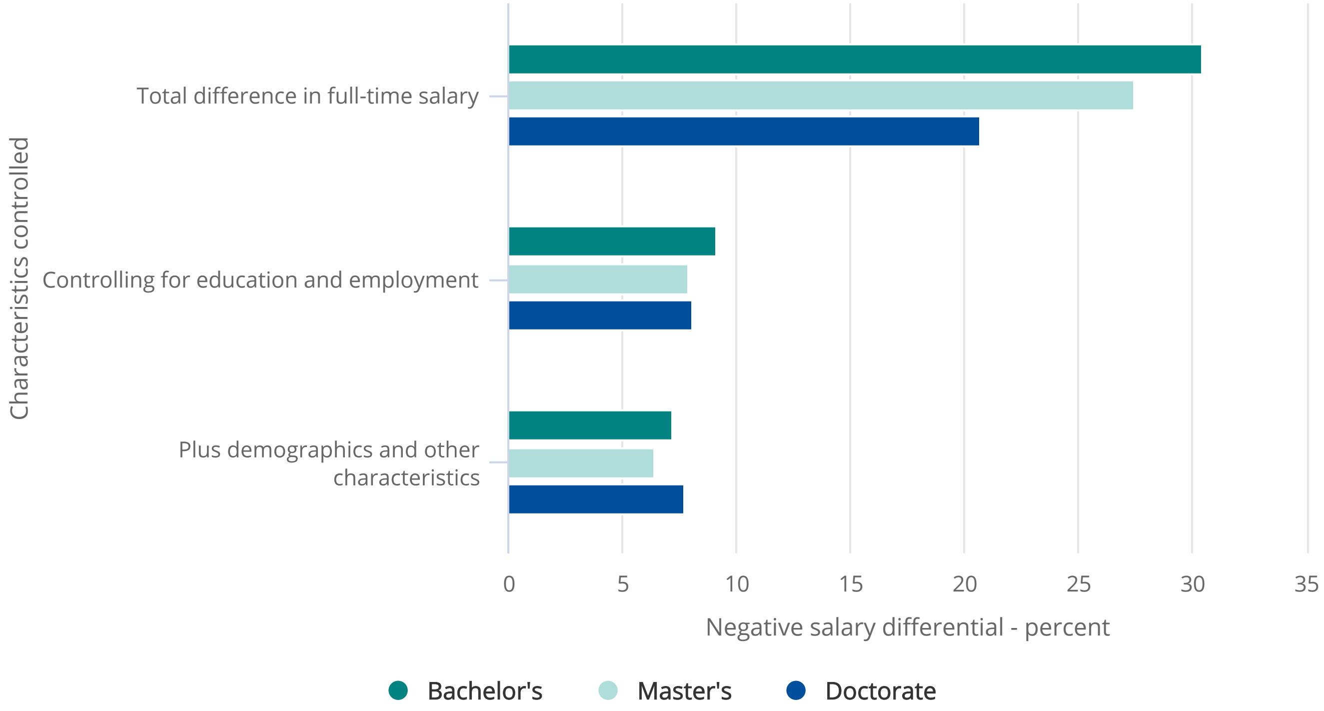
Controlling for the effects of differences in field of highest degree, degree-granting institution, field of occupation, employment sector, and experience,[3] the estimated salary difference between men and women narrows by more than half (Figure 3-30). However, women still earn 9% less than men among individuals whose highest degree is at the bachelor's level, and 8% less than men among individuals whose highest degree is at the master's or doctoral level. The pattern by degree level is similar among racial and ethnic groups: compared with whites and Asians, S&E highest degree holders in other racial and ethnic groups working full time earn 9% and 5% less for the bachelor's and doctoral degree levels, respectively (Figure 3-31). [4]

The analysis of salary differences suggests that attributes related to human capital (fields of education and occupation, employment sector, and experience) rather than socioeconomic and demographic attributes have a greater influence in explaining the salary differences observed among S&E highest degree holders by sex and across racial and ethnic groups. Nonetheless, the analysis also shows that measurable differences in human capital do not entirely explain income differences between demographic groups.[5]

Readers should keep in mind that the interaction between demographic attributes and those related to human capital are complicated. For instance, among scientists and engineers who are not working, women are more likely than men to report family reasons for not working, and this pattern is quite robust across race and ethnic groups (it holds for Asians, whites, and underrepresented minorities). Furthermore, women who remain in the workforce may choose labor-force pathways that are more amenable to having a family. For example, among scientists and engineers who work part time, women are more likely than men to cite family reasons for working part time.[6] These factors are likely to affect labor market outcomes for women and thus complicate the analysis involving human capital, demographic attributes, and salary differences.

FIGURE 3-30

Estimated salary differences between women and men with highest degree in S&E employed full time, controlling for selected characteristics, by degree level: 2015



Note(s)

Salary differences represent the estimated percentage difference in women’s average full-time salary relative to men’s average full-time salary. Coefficients are estimated in an ordinary least squares regression model using the natural log of full-time annual salary as the dependent variable and then transformed into percentage difference. Controlling for education and employment includes 20 field-of-degree categories (out of 21 S&E fields), 38 occupational categories (out of 39 categories), 6 employment sector categories (out of 7 categories), years since highest degree, and years since highest degree squared. In addition to the above education- and employment-related variables, plus demographics and other characteristics includes the following indicators: nativity and citizenship, race and ethnic minority, marital status, disability, number of children living in the household, geographic region (classified into 9 U.S. Census divisions), and whether either parent holds a bachelor's or higher-level degree.

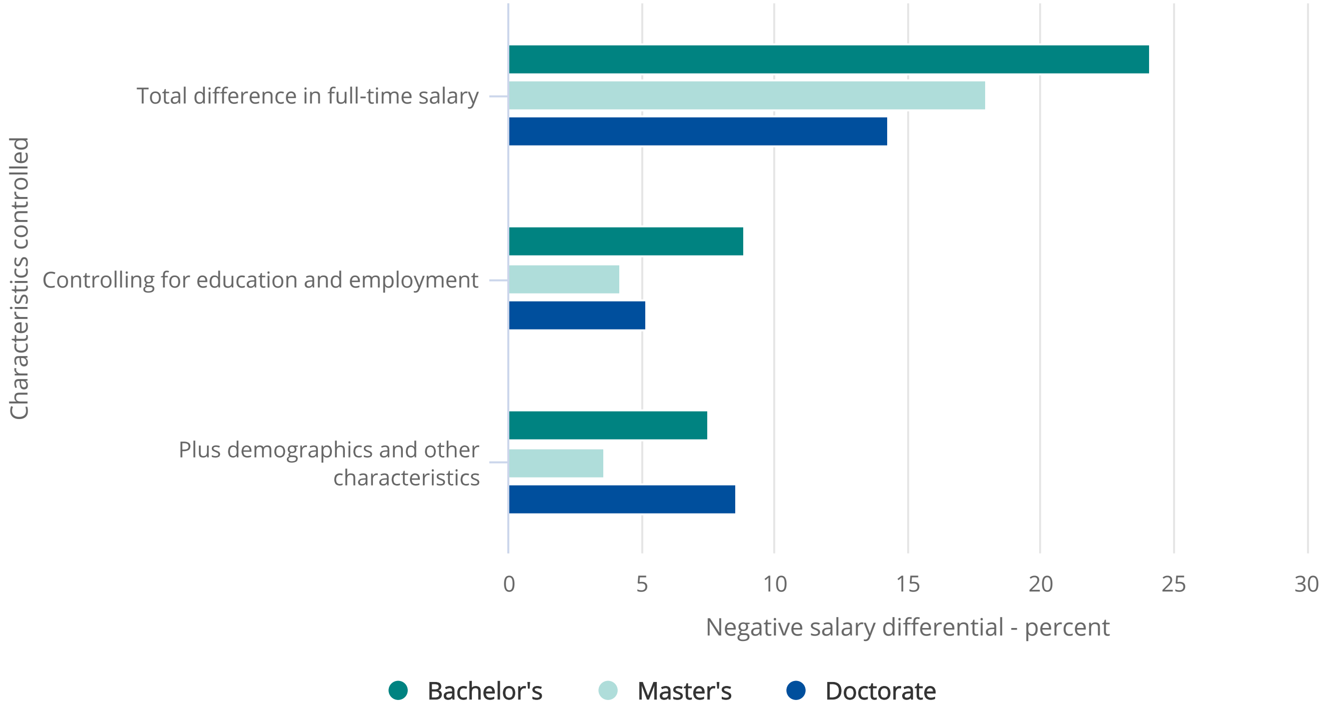
Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Survey of College Graduates (NSCG) (2015), https://www.nsf.gov/statistics/srvygrads/, and the Survey of Doctorate Recipients (SDR) (2015), https://www.nsf.gov/statistics/srvydoctoratework/.

Science and Engineering Indicators 2018

FIGURE 3-31

Estimated salary differences between minorities and whites and Asians with highest degree in S&E employed full time, controlling for selected characteristics, by degree level: 2015



Note(s)

The estimates for master's degrees in the "controlling for education and employment" and "plus demographics and other characteristics" categories are not statistically significant at the 90% confidence level. Salary differences represent the estimated percentage difference in the average full-time salary of minorities relative to the average full-time salary of whites and Asians. Coefficients are estimated in an ordinary least squares regression model using the natural log of full-time annual salary as the dependent variable and then transformed into percentage difference. Minorities include American Indians or Alaska Natives, blacks, Hispanics (of any race), Native Hawaiians or Other Pacific Islanders, and those reporting more than one race. Controlling for education and employment includes 20 field-of-degree categories (out of 21 S&E fields), 38 occupational categories (out of 39 categories), 6 employment sector categories (out of 7 categories), years since highest degree, and years since highest degree squared. In addition to the above education- and employment-related variables, plus demographics and other characteristics includes the following indicators: nativity and citizenship, sex, marital status, disability, number of children living in the household, geographic region (classified into 9 U.S. Census divisions), and whether either parent holds a bachelor's or higher-level degree.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Survey of College Graduates (NSCG) (2015), https://www.nsf.gov/statistics/srvygrads/, and the Survey of Doctorate Recipients (SDR) (2015), https://www.nsf.gov/statistics/srvydoctoratework/.

Science and Engineering Indicators 2018

Effects of Demographic and Other Factors on Salary Differences

Salaries vary by factors beyond education, occupation, and experience. For example, marital status, the presence of children, parental education, and other personal characteristics are often associated with salary differences. These differences reflect a wide range of issues, including (but not limited to) factors affecting individual career- and education-related decisions, differences in how individuals balance family obligations and career aspirations, and productivity and human capital differences among workers that surveys do not measure, and possible effects of employer prejudice or discrimination. Salaries also differ across regions, partly reflecting differences in the cost of living across geographic areas.

However, adding such measures of personal and family characteristics to education, occupation, and experience results in only marginal changes in the estimated salary differences between men and women, and among racial and ethnic groups,[7] compared with estimates that account for education, occupation, and experience alone. Women's adjusted salary differentials are 8% among S&E doctorates—7% among S&E bachelor's degree and 6% among master's degree holders (Figure 3-30). Adjusted salary differences among racial and ethnic groups are approximately 8% and 9% among bachelor's degree and doctorate holders, respectively (Figure 3-31).[8]

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[1] In this chapter, American Indian or Alaska Native, Asian, black, Native Hawaiian or Other Pacific Islander, white, and more than one race refer to individuals who are not of Hispanic origin. Hispanics may be any race.

[2] Salary differences represent estimated percentage differences in women's reported full-time annual salary relative to men's reported full-time annual salary as of February 2015. Coefficients are estimated in an ordinary least squares regression model using a natural log of full-time annual salary as the dependent variable. This estimated percentage difference in earnings differs slightly from the observed difference in median earnings by sex because the former addresses differences in mean earnings rather than median earnings.

[3]Included are 20 NCSES-classified field-of-degree categories (out of 21 S&E fields), 38 NCSES-classified occupational categories (out of 39 categories), 6 NCSES-classified employment sector categories (out of 7), years since highest degree, and years since highest degree squared.

[4] The estimates in Figure 3-31 for the last two models of the master's degree level, 4.2 and 3.6, respectively, are not significant at the 90% confidence level.

[5] The regression analysis addresses major factors that affect differences in earnings but does not attempt to cover all possible sources of difference. For a more detailed discussion on the topic, see Blau and Kahn (2007), Mincer (1974), Polachek (2008), and Xie and Shauman (2003).

[6] See Figures 6-B and 6-C in "Employment Status" from National Science Foundation, National Center for Science and Engineering Statistics (2017).

[7]In addition to the education- and employment-related variables, the following indicators are included in wage regression models: nativity and citizenship, marital status, disability, number of children living in the household, geographic region (classified into nine U.S. Census divisions), and whether either parent holds a bachelor's or higher level degree. The sex regression controls for racial and ethnic minority status, and the race and ethnicity regression controls for sex.

[8] The estimates in Figure 3-31 for the last two models of the master's degree level, 4.2 and 3.6, respectively, are not significant at the 90% confidence level.

Immigration and the S&E Workforce

The industrialized nations of the world have long benefitted from the inflow of foreign-born scientists and engineers and the S&E skills and knowledge they bring. S&E skills are more easily transferrable across international borders than many other skills, and many countries have made it a national priority to attract international talent in S&E (NSB 2008). A large proportion of workers employed in S&E fields in the United States are foreign born. This section presents data on foreign-born scientists and engineers in the U.S. economy, including recent indicators of migration to the United States and the rate at which foreign-born recipients of U.S. doctorates remain in the United States after earning their degree. Data from various sources, including NSF (the NSCG and SED), the Census Bureau, and the U.S. Citizenship and Immigration Services (USCIS) are discussed to study the immigrant S&E workforce in the United States.[1]

Foreign-born is a broad category, ranging from long-term U.S. residents with strong roots in the United States to recent immigrants who compete in global job markets and whose main social, educational, and economic ties are in their countries of origin. When interpreting data on foreign-born workers, the range of individuals in this category should be kept in mind.

Nationally representative survey data, such as NSF and Census survey data, although collected in different ways, yield broadly consistent estimates of the number of foreign-born scientists and engineers in the United States. In 2015, foreign-born individuals accounted for 29% to 30% of college-educated workers employed in S&E occupations in the United States (Table 3-25), which is higher than their representation in both the overall population (13%) and among all college graduates (17%). Both the number and proportion of foreign-born workers employed in S&E occupations in the United States have risen over time (Table 3-25).

TABLE 3-25

Foreign-born workers in S&E occupations, by education level: 1993, 2003, and 2015

(Percent)

Education	1993	2003		2015	
	SESTAT	SESTAT	ACS	NSCG	ACS
All college educated	15.8	22.6	25.2	30.0	28.8
Bachelor's	11.4	16.4	18.7	21.2	21.1
Master's	20.7	29.4	32.0	40.6	38.2
Doctorate	26.8	36.4	38.7	42.3	45.3

ACS = American Community Survey; NSCG = National Survey of College Graduates; SESTAT = Scientists and Engineers Statistical Data System.

Note(s)

All college educated includes professional degree holders not broken out separately. The data from the ACS include all S&E occupations except postsecondary teachers of S&E because these occupations are not separately identifiable in the ACS data files.

Source(s)

Census Bureau, ACS Public Use Microdata Sample (PUMS) (2003, 2015); National Science Foundation, National Center for Science and Engineering Statistics, SESTAT (1993, 2003), https://www.nsf.gov/statistics/sestat/, and NSCG (2015), https://www.nsf.gov/statistics/srvygrads/.

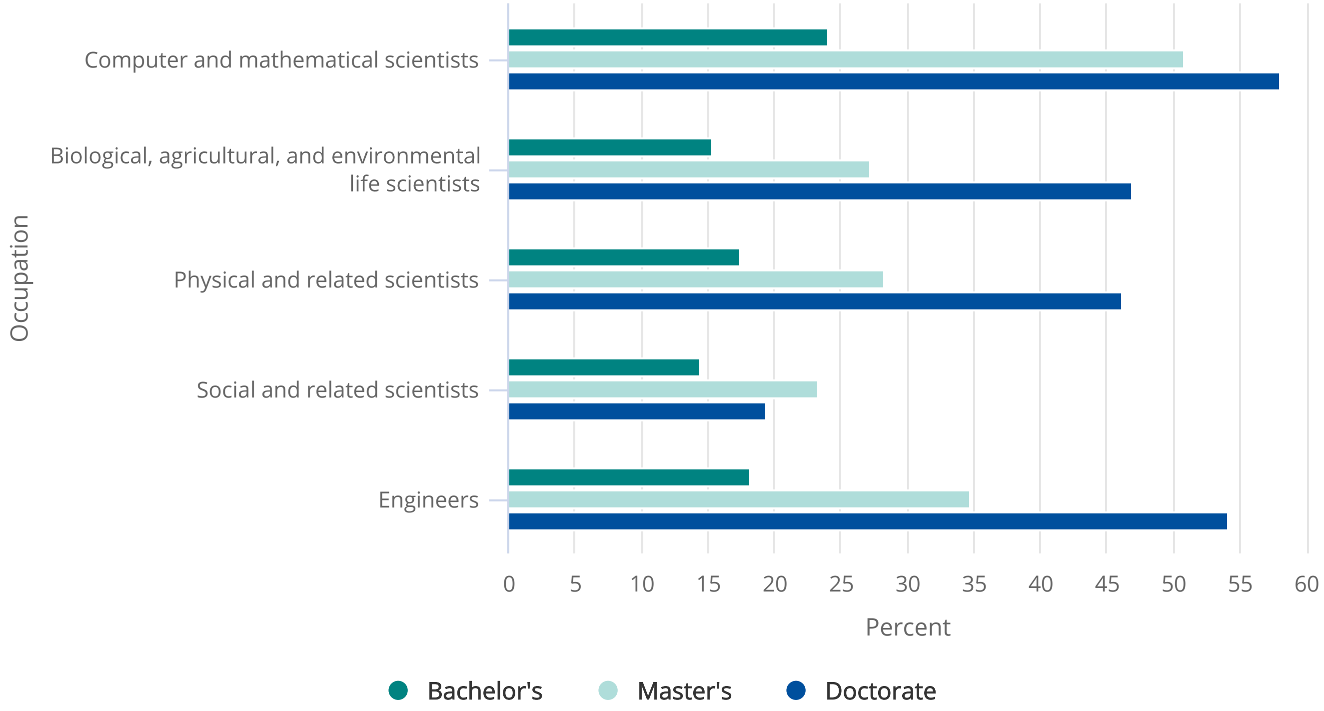
Science and Engineering Indicators 2018

Characteristics of Foreign-Born Scientists and Engineers

Foreign-born workers employed in S&E occupations tend to have higher levels of education than their U.S. native-born counterparts. Among individuals employed in S&E occupations, 17% of foreign-born workers have a doctorate, compared to 10% of U.S. native-born individuals in these occupations. In most S&E occupations, the higher the degree level, the greater the proportion of the workforce who are foreign born (Figure 3-32). This association is strongest among computer and mathematical scientists and engineers. In 2015, at the bachelor's degree level, the proportion of foreign-born individuals in S&E occupations ranged from 14% (social scientists) to 24% (computer and mathematical scientists). However, at the doctoral level, over 45% were foreign born in each S&E occupation except social sciences.

FIGURE 3-32

Foreign-born scientists and engineers employed in S&E occupations, by highest degree level and broad S&E occupational category: 2015



Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Survey of College Graduates (NSCG) (2015), https://www.nsf.gov/statistics/srvygrads/.

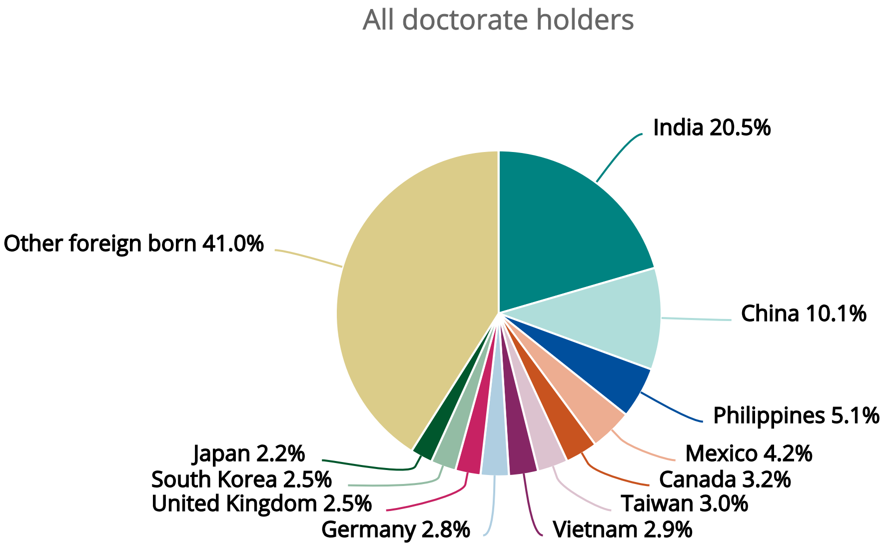
Science and Engineering Indicators 2018

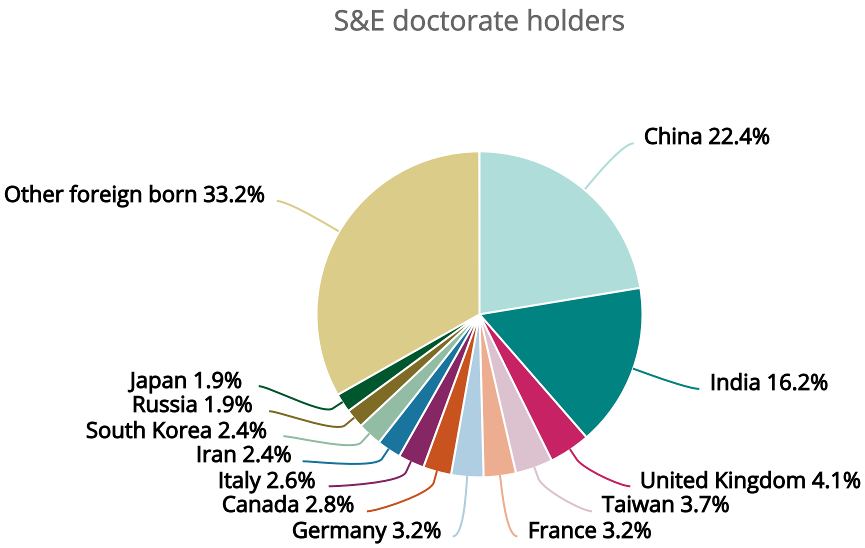
In 2015, among scientists and engineers employed in S&E occupations, foreign-born workers (median age 39 years) were younger than their native-born counterparts (median age 42 years). The distribution by sex was largely similar across foreign-born (30% female) and native-born (28% female) workers in S&E occupations. Asians accounted for 61% of foreign-born workers in S&E occupations but for only 3% of U.S. native-born workers in these occupations (Appendix Table 3-19). In comparison, whites represented 24% of foreign-born workers in S&E occupations but 85% of native-born workers in these occupations. Nearly 90% of all Asians employed in S&E occupations were foreign born.

In 2015, 58% of foreign-born individuals in the United States with an S&E highest degree were from Asia; another 13% were from Europe. North and Central America, the Caribbean, South America, and Africa each supplied from 3% to 5% of the foreign-born S&E highest degree holders in the United States. In 2015, the leading country of origin among these immigrants was India, which accounted for 21% of the foreign-born S&E degree holders in the United States (Figure 3-33). With nearly half the total for India, China was the second leading country with 10%. Source countries for the 464,000 foreign-born holders of S&E doctorates were somewhat more concentrated, with China providing a higher proportion (22%) than India (16%). These patterns by source region and country for foreign-born S&E highest degree holders in the United States have been stable since at least 2003.

FIGURE 3-33

Foreign-born individuals with highest degree in S&E living in the United States, by place of birth: 2015





Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Survey of College Graduates (NSCG) (2015), https://www.nsf.gov/statistics/srvygrads/.

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The NSCG asks respondents to provide information on where they received their postsecondary degrees and their motivation for coming to the United States. This information sheds light on the educational and career paths of foreign-born scientists and engineers in the United States and possible factors that influence these paths. Approximately half of foreign-born scientists and engineers in the United States received their initial university training abroad. In 2015, there were about 5.1 million college-educated, foreign-born scientists and engineers employed in the United States; of these, 2.5 million received their first bachelor's degree abroad. Many of these individuals came to the United States for job or economic opportunities (34%), family-related reasons (26%), or educational opportunities (29%). In contrast, only 7% of foreign-born scientists and engineers with a U.S. bachelor's degree cited job or economic opportunities, and many more cited family-related reasons (44%) or educational opportunities (24%) as their primary reasons for coming to the United States.

A substantial number of foreign-born scientists and engineers in the United States appear to come here for further higher education after receiving their initial university training abroad. Nearly two-thirds (62%) of the 1.3 million employed foreign-born scientists and engineers who received their initial university training abroad and who hold a master's degree, doctorate, or professional degree completed their highest degree in the United States. Among these individuals, the most frequently cited reason for coming to the United States was educational opportunities (62%). Family-related reasons (13%) and job or economic opportunities (15%) were cited by much smaller proportions. Among the foreign-born doctorate holders employed in the United States, 66% received this degree from a U.S. institution.

New Foreign-Born Workers

During the 2007–09 economic downturn, two indicators—the number of temporary work visas issued by the U.S. government in visa classes for high-skill workers and the stay rates of foreign-born U.S. doctorate recipients—showed evidence that the volume of new foreign-born workers entering the U.S. S&E workforce might be declining. However, recent data indicate that this period of decline was temporary. In addition to these two indicators, this section discusses characteristics of workers with temporary work visas and country profiles of new foreign-born workers.

Temporary Visas

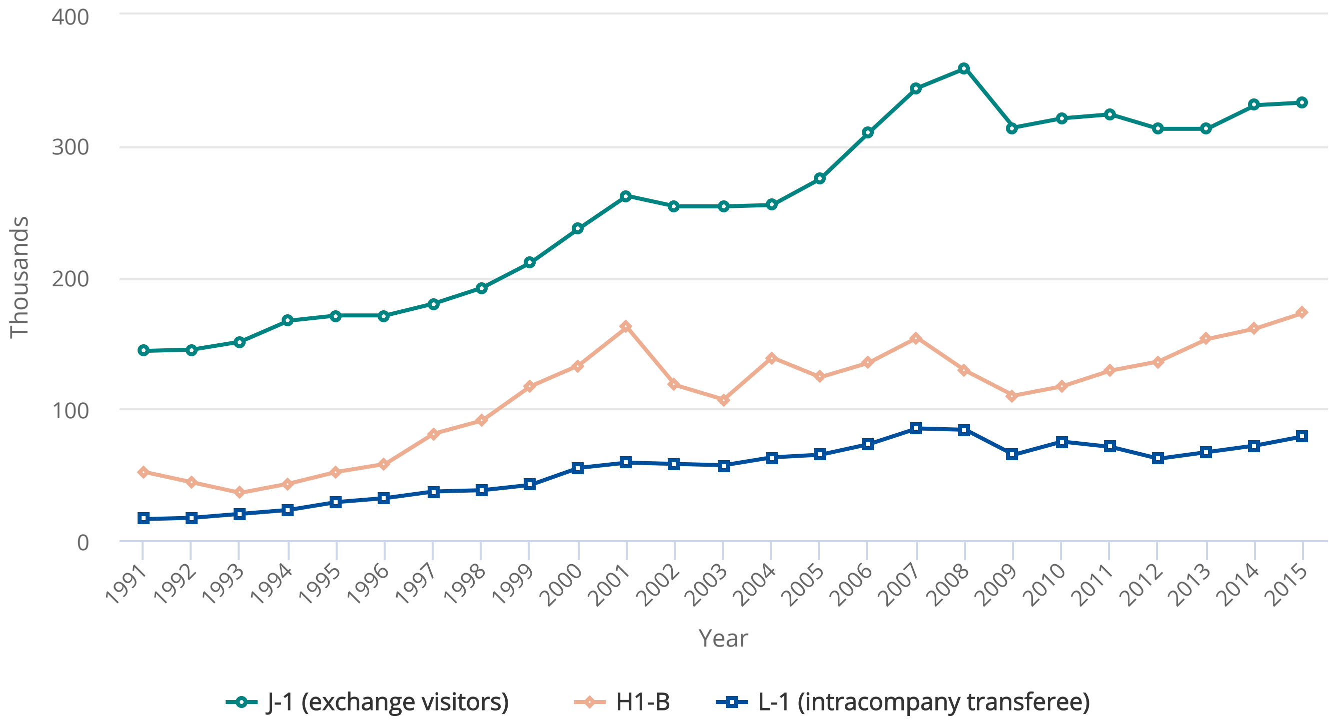
The number of temporary work visas issued for high-skill workers provides an indication of how many new immigrant workers are entering the U.S. labor force.[2] After several years of growth, the largest classes of these temporary visas declined during the recent economic downturn. Despite the increases in the issuance of temporary visas since FY 2009, the total numbers of visas issued in some categories have not yet reached the recent highs seen in FY 2007, before the beginning of the economic downturn (Figure 3-34). A decline in the issuance of these visas, particularly H-1B visas, also occurred following the milder recession in 2001.

H-1B visas account for a significant proportion of foreign-born high-skill workers employed by U.S. firms on temporary visas. This type of visa is issued to individuals who seek temporary entry into the United States in a specialty occupation that requires professional skills. It is issued for up to 3 years, with the possibility of an extension to 6 years. In 2015, the United States issued about 173,000 H-1B visas, up 57% from the recent low in 2009 (110,000) and higher than the recent peak in 2007 (154,000).

Issuance of visas in other temporary work categories that usually contain large numbers of high-skill workers has also risen since 2009; however, the H-1B visa category has shown continued increase since 2009, unlike certain other visa classes such as the J-1 and L-1 categories.

FIGURE 3-34

Temporary work visas issued in categories with many high-skill workers: FYs 1991–2015



Note(s)

J-1 exchange visitor visa is used for many different skill levels.

Source(s)

U.S. Department of State, Nonimmigrant Visa Issuances by Visa Class and by Nationality, and Nonimmigrant Visas by Individual Class of Admission, https://travel.state.gov/content/visas/en/law-and-policy/statistics/non-immigrant-visas.html (accessed 17 January 2017).

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Characteristics of H-1B Visa Recipients

The majority of H-1B visa recipients work in S&E or S&E-related occupations. However, precise counts of H-1B visas issued to individuals in these occupations cannot be obtained because USCIS does not classify occupations with the same taxonomy used by NSF. In FY 2016, workers in computer-related occupations as classified by USCIS were the most common recipients of H-1B visas, accounting for 61% of new H-1B visas issued (Appendix Table 3-20). The total number of newly initiated H-1B visas for workers in computer-related fields has increased substantially since 2010, following a steep decline between 2008 and 2009 during the economic downturn (DHS/USCIS 2010, 2012, 2013, 2015, 2016, 2017). The proportion of H-1B recipients who worked in computer sciences was considerably lower in the earlier part of the 2000s. For example, in 2002, only 25% of H-1B visa recipients worked in computer-related fields (NSB 2012).

H-1B visa recipients tend to possess a bachelor's or higher-level degree. In FY 2016, nearly half of new H-1B visa recipients (44%) had a bachelor's degree; the rest (55%) had an advanced degree, including 45% with a master's degree, 3% with a professional degree, and 7% with a doctorate (DHS/USCIS 2017). In FY 2016, 62% of new H-1B visa recipients were from India, and 15% were from China (DHS/USCIS 2017). The preponderance of advanced degrees notwithstanding, H-1B visa recipients were relatively young. In FY 2016, 41% of new H-1B visa recipients were between the ages of 25 and 29, and 30% were between the ages of 30 and 34 (DHS/USCIS 2017).

▦ Table 3-26 shows the starting salaries of new recipients of H-1B visas by occupation group. These starting salaries are reported by employers in the final visa application forms sent to USCIS and differ from the H-1B salaries that firms report earlier in the process on their applications to the Department of Labor. The relatively low median salaries for workers in life sciences may reflect the use of H-1B visas to hire individuals for relatively low-paying postdoc positions.

TABLE 3-26

Annual salaries for new H-1B visa recipients, by occupation: FY 2016

(Dollars)

Occupation	Median	Mean
Administrative specializations	62,000	74,000
Architecture, engineering, and surveying	75,000	83,000
Art	56,000	71,000
Computer-related occupations	72,000	80,000
Education	55,000	68,000
Entertainment and recreation	61,000	71,000
Law and jurisprudence	105,000	116,000
Life sciences	52,000	63,000
Managers and officials	71,000	83,000
Mathematics and physical sciences	75,000	81,000
Medicine and health	70,000	119,000
Miscellaneous professional, technical, and managerial	84,000	93,000
Museum, library, and archival sciences	44,000	51,000
Religion and theology	36,000	40,000
Social sciences	88,000	104,000
Writing	45,000	52,000

Source(s)

Department of Homeland Security, U.S. Citizenship and Immigration Services, *Characteristics of H-1B Specialty Occupation Workers, Fiscal Year 2016 Annual Report to Congress* (May 5,2017), https://www.uscis.gov/sites/default/files/USCIS/Resources/Reports%20and%20Studies/H-1B/h-1B-FY16.pdf.

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Short-Term Stay Rates for U.S. S&E Doctorate Recipients

Among doctorate recipients, the period immediately after earning their doctorate is a pivotal point that can substantially affect long-term career trajectories. During this period, foreign-born doctorate recipients who remain in the United States may set themselves on a path to long-term residency.

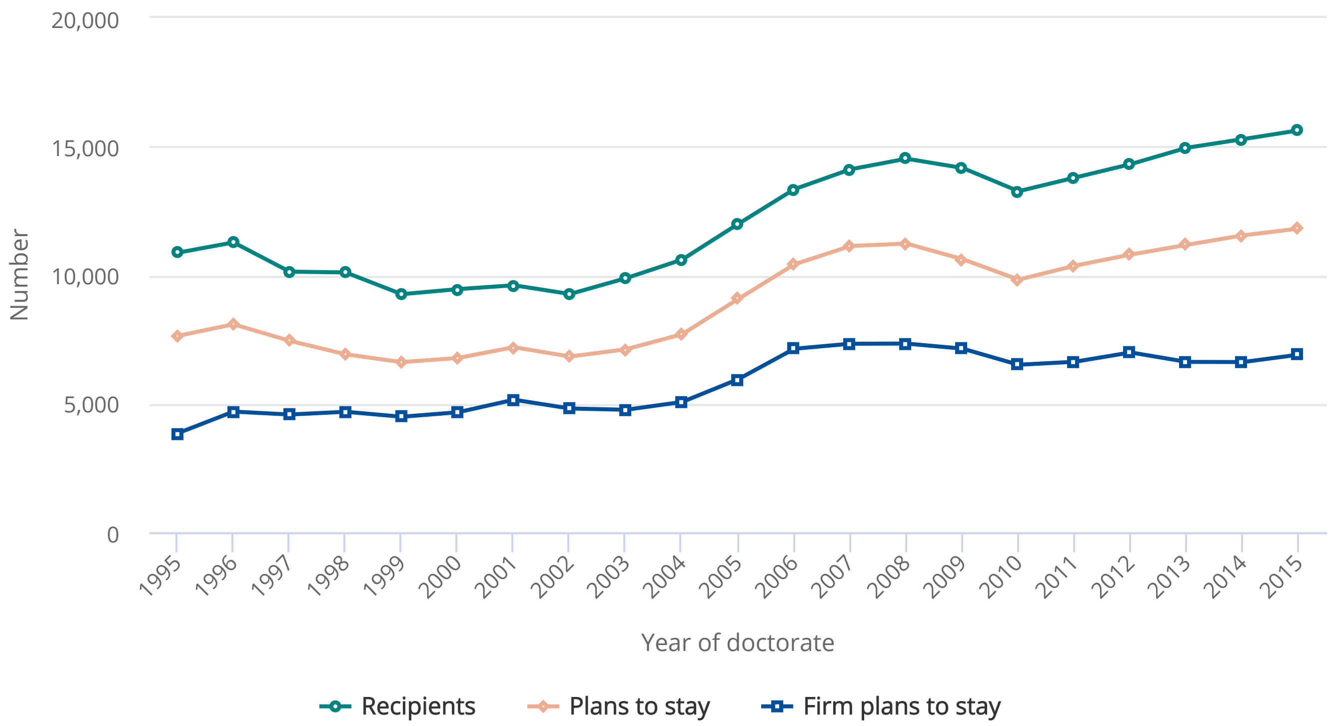
At the time that they receive their doctorates, foreign-born students at U.S. universities report whether they intend to stay in the United States and whether they have a firm offer to work in the United States (either a postdoc or a job) the following year.[3] These responses provide estimates of short-term stay rates.[4]

Most foreign-born noncitizen recipients of U.S. S&E doctorates (including those on temporary and permanent visas) plan to stay in the United States after graduation (Figure 3-35). According to the most recent 2015 estimates, at the time of doctorate receipt, 76% of foreign-born noncitizen recipients of U.S. S&E doctorates planned to stay in the United States, and 44% had either accepted an offer of postdoc study or employment or were continuing employment in the United States. Both of these proportions have risen since the 1980s. In 1995, 70% planned to stay in the United States after graduation, and 35% said they had firm offers in hand. Throughout the 1980s, these proportions were about 50% and 33%, respectively (NSB 2012).

Although stay rates have risen over an extended period, they have fluctuated within a relatively narrow range since the beginning of the 2000s (Figure 3-35; Appendix Table 3-21). Among foreign-born S&E doctorate recipients, both the percentage reporting plans to stay in the United States and the percentage reporting firm offers to stay have declined since the years just before 2008–2011, a period marked by the economic downturn and its aftermath. The overall number of foreign-born S&E doctorate recipients also declined in 2009 and 2010, although the numbers have since risen, and the 2015 level exceeded the recession-era peak seen in 2008.

FIGURE 3-35

Plans at graduation of foreign recipients of U.S. S&E doctoral degrees to stay in the United States, by year of doctorate: 1995–2015



Note(s)

Data include foreign doctorate recipients on temporary and permanent visas and also those with unknown visa status.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2016), Survey of Earned Doctorates (SED) (2015).

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Overall, S&E short-term stay rates are high in the mathematics and computer sciences, biological and biomedical sciences, physical and earth sciences, and engineering fields (Appendix Table 3-21). According to the most recent estimates, the short-term stay rates in these four fields ranged from 77% to 81%, as measured by reports of intentions to stay in the United States. However, the short-term stay rates for foreign-born U.S. S&E doctorate recipients in health fields (71%) were somewhat lower, and those in psychology and social sciences (56%) were substantially lower.

Stay rates vary by place of origin. Between 2012 and 2015, the vast majority of U.S. S&E doctorate recipients from China (83%) and from India (87%) reported plans to stay in the United States, and approximately half of these individuals reported accepting firm offers for employment or postdoc research in the United States (Appendix Table 3-21). U.S. S&E doctorate recipients from Japan, South Korea, and Taiwan were less likely than those from China and India to stay in the United States. No more than half of U.S. S&E doctorate recipients from Turkey and Germany had firm plans to stay in the United States after graduation. In North America, the percentage of U.S. S&E doctorate recipients who had definite plans to stay in the United States was higher for those from Canada than for those from Mexico.

Among U.S. S&E doctorate recipients from the two top countries of origin, China and India, the proportions reporting plans to stay in the United States have declined since the mid-2000s (Appendix Table 3-21).

Long-Term Stay Rates for U.S. S&E Doctorate Recipients

Long-term stay rates indicate the degree to which foreign-born noncitizen recipients of U.S. S&E doctorates enter and remain in the U.S. workforce to pursue their careers. For a particular graduating cohort of foreign-born noncitizen S&E doctorate recipients, the proportion of that cohort who report living in the United States a given number of years after receiving their degrees is an indicator of the cohort's long-term stay rate. For example, 10-year and 5-year stay rates in 2015 refer to the proportion of 2005 and 2010 graduating cohorts, respectively, who reported living in the United States in 2015.[5]

Five- and 10-year stay rates by degree field show similar patterns—with the highest stay rates in the computer and mathematical sciences and engineering (Table 3-27). By country of citizenship at time of degree, China and India, two countries that are the source of more S&E doctorate recipients than any other countries, have the highest 5- and 10-year stay rates (Table 3-28). Overall, the 5-year and 10-year stay rates were both 70% in 2015.

TABLE 3-27

Temporary visa holders receiving S&E doctorates in 2010 and 2005 who were in the United States in 2015, by S&E degree field

(Number and percent)

Degree field	2010 foreign doctorate recipients	5-year stay rate (%)	2005 foreign doctorate recipients	10-year stay rate (%)
Total	36,700	70	31,600	70
Biological, agricultural, health, and environmental life scientists	9,100	72	7,400	69
Computer and mathematical scientists	4,900	76	3,700	74
Physical scientists	5,600	66	4,900	69
Social scientists	4,800	49	4,800	51
Engineering	12,300	75	10,900	76

Note(s)

Detail may not add to total because of rounding.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Survey of Doctorate Recipients (SDR) (2015), https://www.nsf.gov/statistics/srvydoctoratework/.

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TABLE 3-28

Temporary visa holders receiving S&E doctorates in 2010 and 2005 who were in the United States in 2015, by country of citizenship at time of degree

(Number and percent)

Country of citizenship	2010 foreign doctorate recipients (number)	5-year stay rate (%)	2005 foreign doctorate recipients (number)	10-year stay rate (%)
Total	36,700	70	31,600	70
China (including Hong Kong)	10,600	85	10,700	90
India	6,300	83	3,500	85
South Korea	3,600	66	3,000	56
West Asia	3,200	61	2,700	56
Europe	3,900	64	3,800	65
North and South America	3,800	53	3,500	50
All other countries	5,400	49	4,500	45

Note(s)

Detail may not add to total because of rounding.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Survey of Doctorate Recipients (SDR) (2015), https://www.nsf.gov/statistics/srvydoctoratework/.

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It is also important to know how these estimates compare with earlier estimates based on previous cohorts so as to determine if the stay rates for more recent cohorts have declined or increased. Figure 3-36 shows the 5- and 10-year stay rates measured every 2 years since 2001 for those on temporary visas at the time they received their degrees. The 5-year stay rate shows increases through 2005, a temporary period of decline in 2007 and 2009, and then increases to the highest levels in 2013 and 2015. The 10-year stay rate also increased substantially from 2001 to 2015. The 2015 stay rates are at an all-time high for temporary visa holders, both 5 years and 10 years after degree receipt.

Figure 3-37 highlights a group of U.S. S&E doctorate recipients who display lower-than-average stay rates. These are temporary visa holders who indicated that they received foreign financial support during graduate school. It is understandable that these doctorate recipients would have closer ties to a foreign country—presumably, in most cases, their home country—and might have both more opportunity and greater sense of obligation to leave after completing the doctorate. However, the vast majority of temporary visa holders do not report foreign support as a primary or secondary source of their graduate study. This was true for 94% of temporary visa holders in 2005 and 95% in 2010. Therefore, even though those who receive foreign support have much lower stay rates, there is little influence on aggregate stay rates due to the small size of the group receiving this type of support.

FIGURE 3-36

Five-year and ten-year stay rates for U.S. S&E doctoral degree recipients with temporary visas at graduation: 2001–15

Note(s)

Data are available for odd-numbered years only.

Source(s)

Finn M, *Stay Rates of Foreign Doctoral Recipients from U.S. Universities*: *2011*, Oak Ridge Institute for Science and Education 2014 (2001–11); National Science Foundation, National Center for Science and Engineering Statistics, Survey of Doctorate Recipients (SDR) (2013, 2015), https://www.nsf.gov/statistics/srvydoctoratework/.

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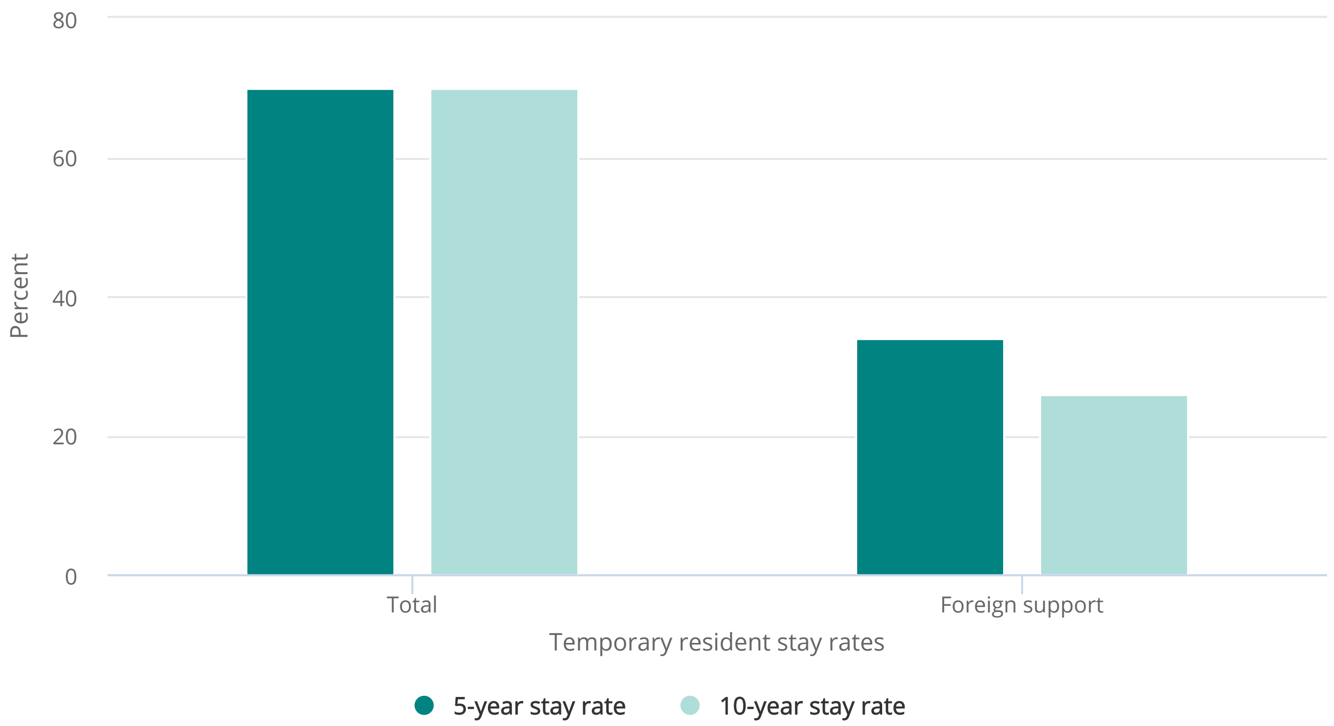
FIGURE 3-37

Five-year and ten-year stay rates for temporary residents receiving S&E doctorates in 2005 and 2010, by foreign support: 2015



Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Survey of Doctorate Recipients (SDR) (2015), https://www.nsf.gov/statistics/srvydoctoratework/.

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[1] For information on high-skill migration worldwide, see Defoort (2008); Docquier and Rapoport (2012); Docquier, Lowell, and Marfouk (2009); and Docquier and Marfouk (2006).

[2] For all types of temporary work visas, the actual number of individuals using them is less than the number issued. For example, some individuals may have job offers from employers in more than one country and may choose not to foreclose any options until a visa is certain.

[3] This question is part of the SED, which is administered to individuals receiving research doctoral degrees from all accredited U.S. institutions. For information on the SED, see https://www.nsf.gov/statistics/srvydoctorates/. The information on plans to stay or definite commitments to stay reflects intentions within the year after graduation as reported by the doctorate recipients around their graduation date. Therefore, any changes in intentions after survey completion are not captured.

[4] Many foreign recipients of U.S. doctorates who report that they plan to stay in the United States the year after graduation may do so using their student (F-1) visa and never obtain a new visa that would permit a longer stay. Student visas permit an additional 12-month stay in the United States after graduation if a student applies for optional practical training (OPT). OPT refers to paid or unpaid work that is performed at least 20 hours a week and that is related to a student's field of study. Starting in May 2016, those earning a degree in STEM fields could apply for an extension of their OPT to a total of 36 months. Data from the Department of Homeland Security's Student and Exchange Visitor Information System (https://www.ice.gov/sevis) show that 68% of students with F-1 visas who completed a doctorate in any field between 1 November 2015 and 31 October 2016 had applied for OPT.

[5] To reduce the standard error of the estimates, a 3-year average was used to calculate the long-term stay rates. For example, the 10-year stay rate was based on the proportion of the 2004, 2005, and 2006 cohorts who reported living in the United States in 2015.

Global S&E Labor Force

The rising emphasis on developing S&E expertise and technical capabilities has been a global phenomenon. S&E work is not limited to developed economies; it occurs throughout the world. However, much of the work is concentrated in developed nations, where a significant portion of R&D also takes place. The availability of a suitable labor force is an important determinant of where businesses choose to locate S&E work (Davis and Hart 2010). Concentrations of existing S&E work, in turn, spawn new employment opportunities for workers with relevant S&E knowledge and skills. As a result, governments in many countries have made increased investments in S&E-related postsecondary education a high priority. At the same time, high-skill workers, including those educated or employed in S&E fields, are increasingly mobile. In recent years, many nations, recognizing the value of high-skill workers for the economy as a whole, have changed their laws to make it easier for such workers to immigrate. These changes indicate an accelerating competition for globally mobile talent (Shachar 2006).

Data on the global S&E workforce are very limited, which makes it difficult to analyze the precise size and characteristics of this specialized workforce. Internationally comparable data are limited to establishment surveys that provide basic information about workers in S&E occupations or on workers with training in S&E disciplines. In contrast, NCSES data on scientists and engineers include far more information on members of the U.S. S&E labor force than is available in other national statistical systems. Additionally, although surveys that collect workforce data are conducted in many OECD member countries, they do not cover several countries—including Brazil and India—that have high and rising levels of S&T capability, and they do not provide fully comparable data for China.

This section provides information about the size and growth of workforce segments whose jobs involve R&D in nations for which relevant data exist.

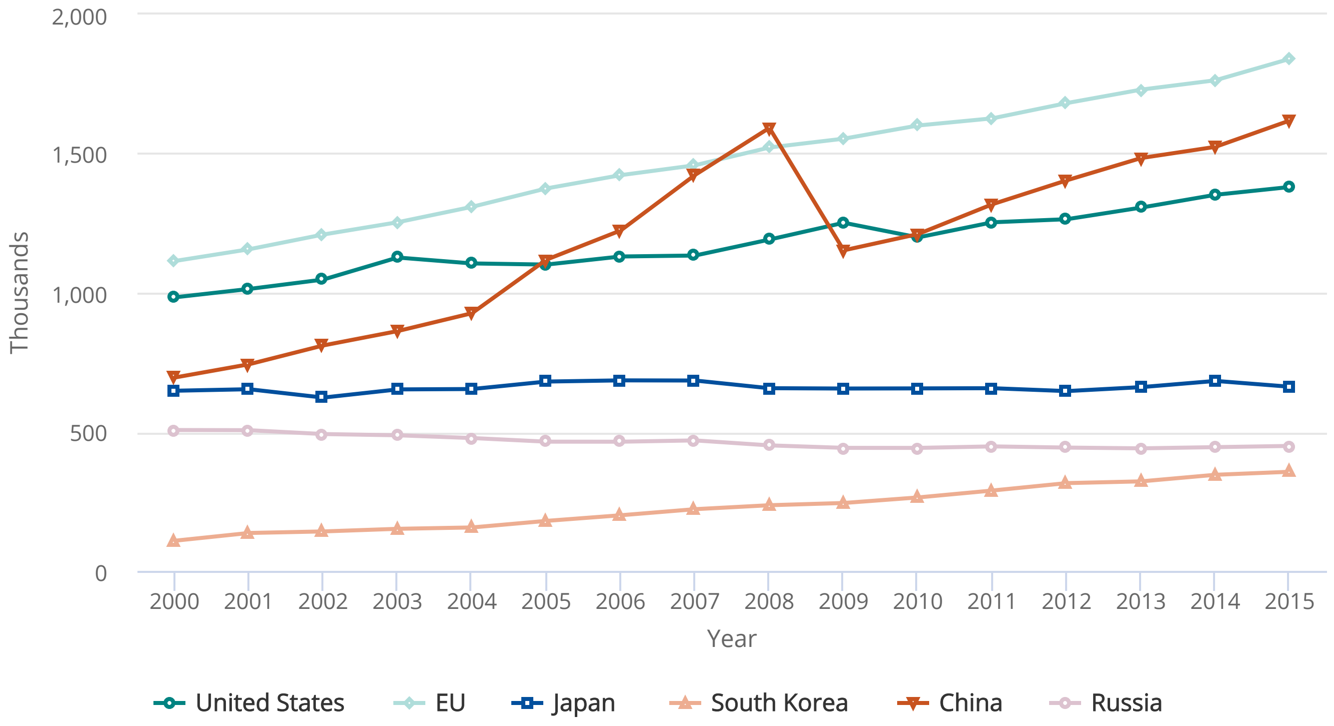
OECD data covering substantial, internationally comparable segments of the S&E workforce provide strong evidence of its widespread, though uneven, growth in the world's developed nations. OECD countries, which include most of the world's highly developed nations, compile data on researchers from establishment surveys in member and selected nonmember countries. These surveys generally use a standardized occupational classification that defines researchers as "professionals engaged in the conception or creation of new knowledge" who "conduct research and improve or develop concepts, theories, models, techniques instrumentation, software or operational methods" (OECD 2015). Because this definition can be applied differently when different nations conduct surveys, international comparisons should be made with caution. OECD also reports data on a broader measure of all personnel employed directly in R&D. In addition to researchers, the data on total R&D personnel include those who provide direct services to R&D, such as clerical and administrative staff employed in R&D organizations.

OECD reports an estimated increase in the number of researchers in its member countries from 3.1 million in 2000 to 4.8 million in 2015. OECD also publishes estimates for seven nonmember economies, including China and Russia. Adding these to the OECD member total for 2015 yields a worldwide estimate of 7.1 million researchers. However, numerous uncertainties affect this estimate, including (but not limited to) lack of coverage of countries with significant R&D enterprise as well as methodological inconsistencies over time and across countries. For example, some nonmember countries that engage in large and growing amounts of research (e.g., India, Brazil) are omitted entirely from these totals. In addition, for some countries and regions, including the United States and the European Union (EU; see Glossary for member countries), OECD estimates are derived from multiple national data sources and not from a uniform or standardized data collection procedure. For example, China's data from 2009 onward have been collected in accordance with OECD definitions and standards, whereas the data before 2009 are not consistent with OECD standards. South Korea's data before 2007 exclude social sciences and humanities researchers and are therefore not consistent with the data from 2007 onward.

Despite these limitations for making worldwide estimates of the number of researchers, the OECD data provide a reasonable starting point for estimating the rate of worldwide growth. For most economies with large numbers of researchers, the number of researchers has grown substantially since 2000 (Figure 3-38). China, whose pre-2009 data did not entirely correspond to the OECD definition, reported more than twice the number of researchers in 2008 than in 2000 and, likewise, reported substantial growth since the end of the recession in 2009. South Korea nearly doubled its number of researchers between 2000 and 2006 and continued to grow strongly between 2007 and 2015. The United States and the EU experienced steady growth but at a lower rate; the number of researchers grew 40% in the United States between 2000 and 2015 and 65% in the EU between 2000 and 2015. Exceptions to the overall worldwide trend included Japan (which experienced a relatively small change of about 2%) and Russia (which experienced a decline; see also Gokhberg and Nekipelova [2002]). Trends in numbers of full-time equivalent R&D personnel were generally parallel to those for researchers in those cases for which both kinds of data are available (Appendix Table 3-22).

FIGURE 3-38

Estimated number of researchers in selected regions or countries: 2000–15



EU = European Union.

Note(s)

Data are not available for all regions or countries for all years. Researchers are full-time equivalents. Counts for China before 2009 are not consistent with Organisation for Economic Co-operation and Development (OECD) standards. Counts for South Korea before 2007 exclude social sciences and humanities researchers.

Source(s)

OECD, Main Science and Technology Indicators (2017/1), https://www.oecd.org/sti/msti.htm, accessed 22 September 2017.

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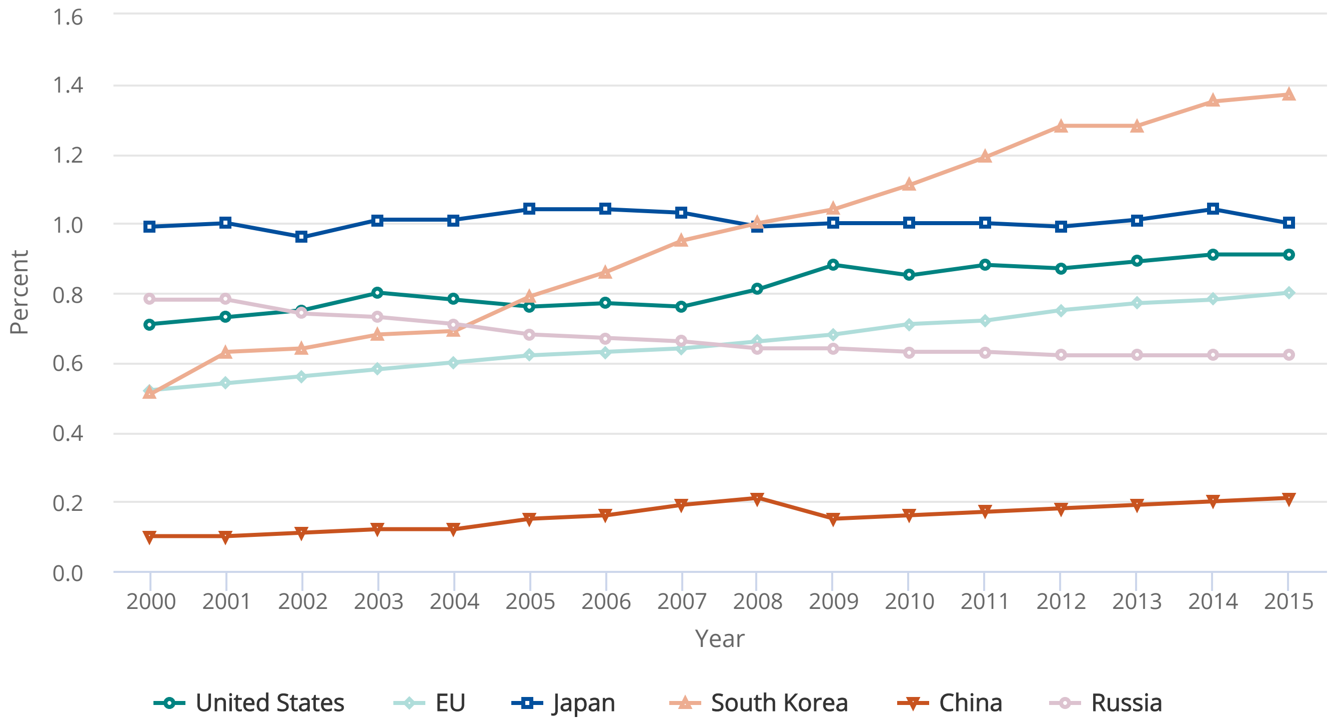
OECD also estimates the proportion of researchers in the workforce. In OECD's most recent estimates, small economies in Scandinavia (Denmark, Finland, Norway, Sweden) reported that between 1% and 2% of their employed workforce are researchers; small economies in East Asia (Singapore, Taiwan) reported that about 1% of their workforce are researchers (Appendix Table 3-23). Among economies with more than 200,000 researchers, OECD's latest estimates are that researchers make up the highest proportions of the workforce in South Korea (1.4%), Japan (1.0%), the United States (0.9%), and the United Kingdom (0.9%). Although China reported a large number of researchers, these workers represent a much smaller percentage of China's workforce (0.2%) than in OECD member countries. Additionally, China and South Korea have shown marked increases in the percentage of their workforce employed as researchers (Figure 3-39). Since 2000, this percentage remained mostly steady in Japan, rose slightly in the United States, and rose steadily in the EU.

FIGURE 3-39

Researchers as a share of total employment in selected regions or countries: 2000–15



EU = European Union.

Note(s)

Data are not available for all regions or countries for all years. Researchers are full-time equivalents. Counts for China before 2009 are not consistent with Organisation for Economic Co-operation and Development (OECD) standards. Counts for South Korea before 2007 exclude social sciences and humanities researchers.

Source(s)

OECD, Main Science and Technology Indicators (2017/1), https://www.oecd.org/sti/msti.htm, accessed 22 September 2017.

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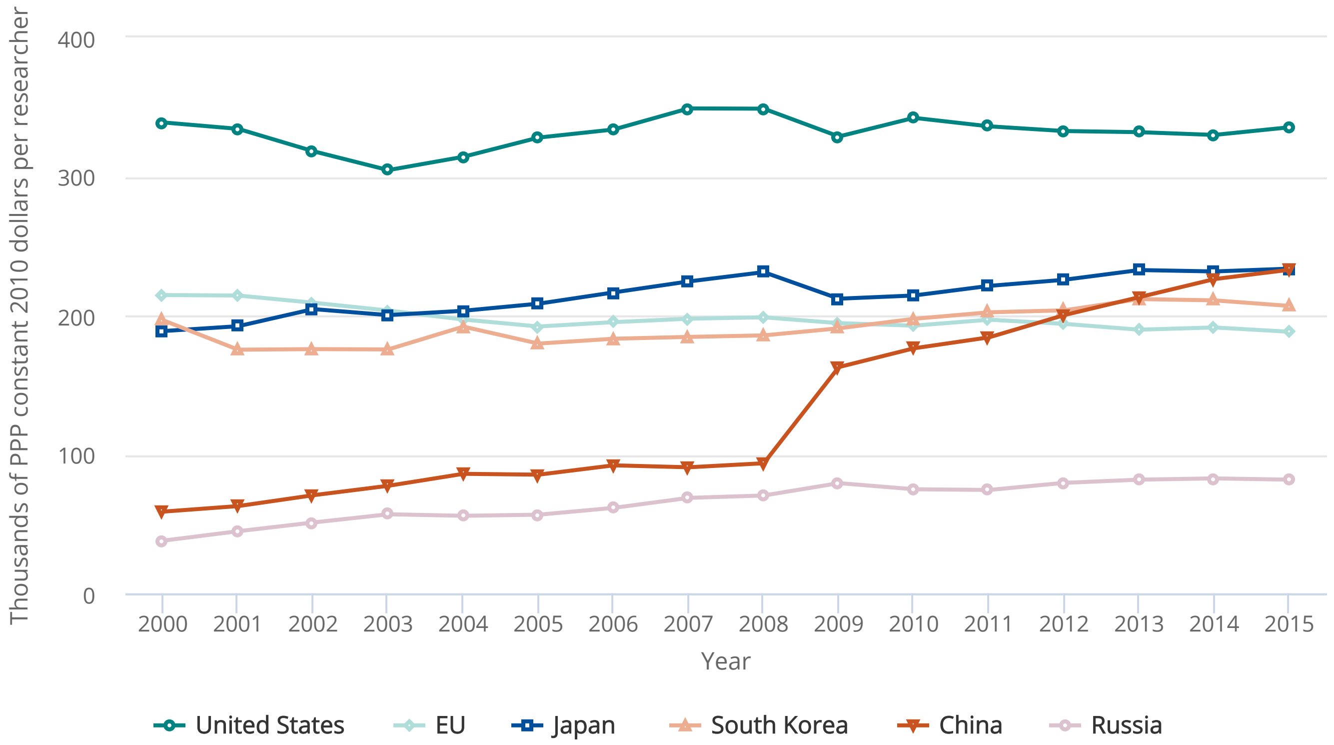
The proportion of female researchers varies considerably across OECD economies. According to the most recent estimates for the selected OECD countries for which data by sex are available, Japan (15% women) and South Korea (19% women) have a significant imbalance among researchers. By comparison, several European countries such as Belgium, Italy, Finland, Sweden, Spain, Norway, United Kingdom, Russia, and Poland, and several other countries such as Turkey and Singapore are more balanced, with women representing between 30% and 46% of researchers. In France and Germany, just over one-quarter of researchers are women.

OECD also provides data on gross domestic expenditures on R&D (GERD), which covers all R&D performed within the region, country, or economy in a given year. The data on GERD may be combined with the data on researchers to get an estimate of R&D spending per researcher, which is another useful indicator of national resources devoted to advancing science and engineering. According to the most recent estimates, the United States, Germany, and Austria have the highest R&D expenditures per researcher (Appendix Table 3-23). Japan, South Korea, and China spend relatively similar amounts per researcher, although the number of researchers as a proportion of total employment is significantly lower in China than in Japan and South Korea. Other countries with large numbers of researchers, such as Canada, the United Kingdom, Spain, and Russia, spend much less. Additionally, since 2000, GERD per researcher (in constant prices and purchasing power parity) has fluctuated within a relatively narrow range in the United States, the EU, and South Korea (Figure 3-40). China, whose pre-2009 data did not entirely correspond to the OECD definition, reported nearly 60% more GERD per researcher in 2008 than in 2000, and this number continued to grow between 2009 and 2015.

FIGURE 3-40

Gross domestic expenditures on R&D (GERD) per researcher in selected regions or countries: 2000–15



EU = European Union; PPP = purchasing power parity.

Note(s)

Data are not available for all regions or countries for all years. Researchers are full-time equivalents. The data for China before 2009 are not consistent with Organisation for Economic Co-operation and Development (OECD) standards. The data for South Korea before 2007 exclude social sciences and humanities R&D.

Source(s)

OECD, Main Science and Technology Indicators (2017/1), https://www.oecd.org/sti/msti.htm, accessed 22 September 2017.

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Conclusion

The S&E workforce may be defined in a variety of ways. At its core are individuals in S&E occupations, but those with S&E degrees who are employed in a variety of other jobs make important contributions to the nation's welfare. Many more individuals hold S&E degrees than work in S&E occupations. Indicative of a knowledge-based economy, many of those in non-S&E occupations report that their work nonetheless requires at least a bachelor's degree level of S&E knowledge and skills.

This suggests that the application of S&E knowledge and technical expertise is widespread across the U.S. economy and not limited to S&E occupations.

In both the United States and the rest of the world, the S&E workforce has experienced strong growth. During the 2007–09 recession, U.S. S&E employment remained more resilient than overall employment. Policymakers with otherwise divergent perspectives agree that jobs involving S&E are good for workers and for the economy as a whole. These jobs pay more, even when compared to non-S&E jobs requiring similar levels of education and comparably specialized skills. Although S&E workers are not totally shielded from joblessness, workers with S&E training or in S&E occupations are less often exposed to periods of unemployment.

Innovation based on S&E R&D is globally recognized as an important vehicle for a nation's economic growth and competitive advantage, and growing numbers of workers worldwide are engaged in research. Growth has been especially marked in rapidly developing economies, such as China and South Korea, that have either recently joined the ranks of the world's developed economies or are poised to do so. Mature developed economies in North America and Europe have maintained slower growth, but the number of researchers in the struggling Japanese economy has somewhat stagnated.

The demographic composition of the S&E workforce in the United States is changing. The baby boom portion of the S&E workforce continues to age into retirement. However, increasing proportions of scientists and engineers are postponing retirement to somewhat later ages. At the same time, members of historically underrepresented groups—women and, to a lesser degree, blacks and Hispanics—have played an increasing role in the S&E labor force; although this has been more the case in some fields (e.g., life sciences and social sciences) than in others (e.g., computer and mathematical sciences, physical sciences, and engineering). Despite the recent increases in S&E participation by women and by racial and ethnic minorities, both groups remain underrepresented in S&E compared to their overall labor force participation. For example, women account for less than one-third of all workers employed in S&E occupations in the United States despite representing half of the college-educated workforce.

The United States has remained an attractive destination for foreign students and workers with advanced S&E training. In the wake of the 2001 recession, there were increases in both temporary work visas and stay rates of foreign recipients of S&E doctorates. Although declines occurred during the 2007–09 economic downturn—a period marked by rising unemployment in the United States—data since the downturn suggest that the decline may have been temporary.

In today's dynamic marketplace, where information flows rapidly and technology is always evolving, labor market conditions change fast. Numerous factors—global competition, demographic trends, aggregate economic activities, and S&E training pathways and career opportunities—will affect the availability of workers equipped with S&E expertise, as well as the kinds of jobs that the U.S. economy generates in the future. As a result, comprehensive and timely analysis of current labor force and demographic trends will play a critical role in providing the information needed to understand the dynamic S&E landscape both in the United States and globally.

Glossary

Definitions

European Union (EU): The EU comprises 28 member nations: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, and the United Kingdom. Unless otherwise noted, Organisation for Economic Co-operation and Development data on the EU include all 28 nations.

Involuntarily out-of-field (IOF) employment: Employment in a job not related to the field of one's highest degree because a job in that field was not available. The IOF rate is the proportion of all employed individuals who report IOF employment.

Labor force: A subset of the population that includes both those who are employed and those who are not working but seeking work (unemployed); other individuals are not considered to be in the labor force.

Organisation for Economic Co-operation and Development (OECD): An international organization of 34 countries headquartered in Paris, France. The member countries are Australia, Austria, Belgium, Canada, Chile, Czech Republic, Estonia, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, South Korea, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom, and United States. Among its many activities, the OECD compiles social, economic, and science and technology statistics for all member and selected nonmember countries.

Postdoc: A temporary position awarded in academia, industry, government, or a nonprofit organization, primarily for gaining additional education and training in research after completion of a doctorate.

Stay rate: The proportion of foreign recipients of U.S. S&E doctorates who stay in the United States after receiving their doctorate.

Workforce: A subset of the labor force that includes only employed individuals.

Key to Acronyms and Abbreviations

ACS: American Community Survey

BLS: Bureau of Labor Statistics

CPS: Current Population Survey

ECDS: Early Career Doctorates Survey

EU: European Union

FedScope: Federal Human Resources Data

FY: fiscal year

GED: General Equivalency Diploma

GERD: gross domestic expenditures on R&D

HHS: Department of Health and Human Services

IOF: involuntarily out-of-field

IPUMS: Integrated Public Use Microdata Series

NAICS: North American Industry Classification System

NCSES: National Center for Science and Engineering Statistics

nec: not elsewhere classified

NECTA: New England City and Town Area

NSB: National Science Board

NSCG: National Survey of College Graduates

NSF: National Science Foundation

NSRCG: National Survey of Recent College Graduates

OECD: Organisation for Economic Co-operation and Development

OES: Occupational Employment Statistics

OPM: Office of Personnel Management

OPT: optional practical training

PPP: purchasing power parity

R&D: research and development

S&E: science and engineering

S&T: science and technology

SDR: Survey of Doctorate Recipients

SED: Survey of Earned Doctorates

SEH: science, engineering, and health

SESTAT: Scientists and Engineers Statistical Data System

SET: science, engineering, and technology

SOC: Standard Occupational Classification

STEM: science, technology, engineering, and mathematics

USCIS: U.S. Citizenship and Immigration Services

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CHAPTER 4

Research and Development: U.S. Trends and International Comparisons

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Highlights

Recent Trends in U.S. R&D Performance

R&D performed in the United States totaled $495.1 billion (current dollars) in 2015 and an estimated $475.4 billion in 2014. These numbers compare to U.S. R&D totals of $433.6 billion in 2012 and $454.0 billion in 2013. In 2008, just ahead of the onset of the main economic effects of the national and international financial crises and the Great Recession, U.S. R&D totaled $404.8 billion.

- These data reflect increases of $20.3 billion in 2013, $21.5 billion in 2014, and $19.7 billion in 2015. These sizeable yearly increases in the U.S. total arise mainly from increased business R&D performance. Across the other main R&D-performing sectors, the annual changes were far smaller—and, in some cases, were declines.
- Adjusted for inflation, growth in U.S. total R&D averaged 1.4% annually over the 7-year period 2008–15, marginally behind the 1.5% average pace of U.S. gross domestic product (GDP) over the same period. By comparison, the average annual rate of growth was notably higher in the prior 10-year period (1998–2008): 3.6% for total R&D and 2.2% for GDP. The smaller rate of growth in 2008–15 partly reflects inclusion of the Great Recession years. Nonetheless, considering only the 5-year period of 2010–15, the average annual pace of growth for total R&D is 2.3%, just ahead of 2.2% for GDP.

The business sector continues to account for most of U.S. R&D performance and funding.

- The business sector performed $355.8 billion of R&D in 2015, or 72% of the U.S. total, drawing on business, federal, and other sources of R&D funding.
- The business sector itself provided $333.2 billion of funding for R&D in 2015, or 67% of the U.S. total, most of which supported R&D performed by business.
- The level of business R&D performance declined in 2009 and 2010, compared with the 2008 level, but returned to an expansionary path in 2011 through 2015. Even with these declines, business R&D performance has continued to account for most of the nation's R&D growth over the last 10 years.
- The academic sector was the second largest performer of U.S. R&D, accounting for $64.7 billion in 2015, or about 13% of the national total.
- The federal government was the second largest funder of U.S. R&D, accounting for $120.9 billion, or 24% of U.S. total R&D performance in 2015.

Most of U.S. basic research is conducted at higher education institutions and is funded by the federal government. However, the largest share of U.S. total R&D is experimental development, which is mainly performed by the business sector. The business sector also performs the majority of applied research. Although the absolute dollar values and actual shares have changed over time, these broad trends have remained mostly consistent for several decades.

- In 2015, basic research was about 17% ($83.5 billion) of total U.S. R&D performance, applied research was 20% ($97.2 billion), and experimental development was about 64% ($314.5 billion).
- Higher education institutions historically have been the main performers of U.S. basic research, and they accounted for just under half (49%) of all U.S. basic research in 2015. The business sector is also now a sizable performer of

basic research, accounting for 26% of the basic research total in 2015. The federal government remained the largest funder of basic research, accounting for about 44% of all such funding in 2015.

- The business sector was the predominant performer of applied research, accounting for 58% of all U.S. applied research in 2015. Business also provided 53% of the funding for the applied research total, with most of this support remaining within the sector. The federal government accounted for 36% of the funding.
- Experimental development was by far the largest component of U.S. R&D. The business sector performed 88% of it in 2015 and provided 82% of the funding. Federal funding accounted for only 16% of this experimental development, with the business sector (especially defense-related industries) and federal intramural laboratories and federally funded R&D centers (FFRDCs) being the largest recipients.

Cross-National Comparisons of R&D Performance

Worldwide R&D performance totaled an estimated $1.918 trillion in 2015, up from $1.415 trillion in 2010 and $722 billion in 2000. Fifteen countries or economies performed $20 billion or more of R&D in 2015, accounting for 85% of the global total. The top rankings at present continue to be dominated by the United States and China.

- The United States remained the largest R&D-performing country in 2015, with gross domestic expenditures on R&D of $497 billion, a 26% share of the global total, and an R&D-to-GDP ratio of 2.7%. China was a decisive second, with R&D expenditures of $409 billion, a 21% global share, and an R&D-to-GDP ratio of 2.1%.
- Japan ($170 billion, 9% global share, ratio of 3.3%) and Germany ($115 billion, 6% global share, ratio of 2.9%) were the comparatively distant third and fourth largest R&D-performing countries. The other 11 countries or economies in the top 15 were South Korea, France, India, the United Kingdom, Brazil, Russia, Taiwan, Italy, Canada, Australia, and Spain—with the annual national R&D expenditure totals ranging from about $61 billion (France) down to $20 billion (Spain).
- Total global R&D increased (current dollars) more than two and a half times from 2000 to 2015. About 19% of this increase reflected the growth of U.S. R&D over this period, 17% from the European Union (EU) as a whole (including Germany, France, and the United Kingdom), as well as 5%–6% each from Japan and South Korea. Nonetheless, the largest contributor by far was China, which accounted for 31% of the decade and a half increase. The pace of growth in China's overall R&D over this period remained exceptionally high, at just over 18% annually (or around 16% adjusted for inflation).
- The U.S. share of worldwide R&D was notably higher in 2000 (37%) than in 2015 (26%), continuing to decline over this 15-year period. The EU also exhibited a decline over the same period: from 25% of the global total in 2000, down to 20% in 2015. The expansion was clearly driven by the economies of East/Southeast and South Asia—including China, Japan, South Korea, India, and Taiwan—which represented 25% of the global R&D total in 2000, rising to about 40% in 2015.

U.S. Business R&D

The business sector remains by far the largest performer in the U.S. R&D system. R&D is performed across a wide range of manufacturing and nonmanufacturing sectors. R&D intensity is concentrated, however, in a few industries.

- The R&D performed domestically by U.S. businesses occurs mainly in five business sectors: chemicals manufacturing (particularly the pharmaceuticals industry); computer and electronic products manufacturing;

transportation equipment manufacturing (particularly the automobile and aerospace industries); information (particularly the software publishing industry); and professional, scientific, and technical services (particularly the computer systems design and scientific R&D services industries).

- In 2015, these five business sectors accounted for 83% of the $355.8 billion total domestic business R&D performance that year. Similarly, in 2008, the five sectors accounted for 84% of the business total.
- Considering U.S. business as a whole, domestic R&D is mainly funded through performing companies' own funds: 83% in 2015 (and similar shares for recent years). For the remaining 17%, where the R&D is performed by companies but funded by others, the largest source of funding is the federal government, whose funding accounted for about 8% of the business R&D performance total in 2015. Other companies located domestically contributed another 4% of the funding, and foreign companies about 5% of the funding. Nonfederal governments and both domestic and foreign nonprofit organizations also were sources but at very small levels. (Some notable departures from these aggregate average shares occur when specific sectors and industries are considered.)
- Large companies (those with 25,000 or more domestic employees) accounted for 36% of all U.S. business R&D performance in 2015. Micro companies (those with 5-9 domestic employees) and small companies (10-49 domestic employees) together accounted for 5%. The other 59% was spread among the size classifications between these extremes. This distribution of business R&D performance share by size has not greatly changed in recent years.

Recent Trends in Federal Support for U.S. R&D

Federal funding for the R&D performed by federal departments and agencies, as well as most of the other major U.S. R&D performers, increased annually (in both current and constant dollar terms) from the late 1990s through FY 2010. Over the years since, however, the levels of federal support have dropped noticeably.

- Federal obligations for the total of R&D and R&D plant were $129 billion in FY 2008, $145 billion in FY 2009, and $147 billion in FY 2010. But the years thereafter have been marked by several large declines—in FYs 2011 and 2013, with only modest offsetting increases in FYs 2012, 2014, and 2015. Federal R&D funding had dropped to $131 billion in FY 2015—a decline of 18% from the FY 2010 level, when adjusted for inflation.
- Fifteen federal departments and 12 other agencies engage in and/or fund R&D in the United States. Eight of these departments or agencies reported R&D obligations in FY 2015 in excess of $1 billion: U.S. Department of Agriculture, Department of Commerce, Department of Defense (DOD), Department of Energy, Department of Health and Human Services (HHS), Department of Homeland Security, National Science Foundation, and National Aeronautics and Space Administration. These together accounted for 97% of all federal obligations for R&D that year.
- DOD has historically accounted for half or more of annual federal R&D funding. Health-related R&D accounts for the majority of federal nondefense R&D funding. DOD and HHS have borne the brunt of the federal R&D funding decline since FY 2010, with the other nondefense categories being much less affected.

Introduction

Chapter Overview

Scientific discoveries, new technologies, and the aggressive application of cutting edge knowledge are essential for success in a competitive global economy. As such, the strength of a country's overall R&D enterprise—including both the public and private realms of this system—is an important marker of current and future national economic advantage.

This chapter identifies the essential current trends in the performance and funding of the U.S. R&D system. The discussion covers the sectors mainly responsible for present U.S. R&D performance and funding: the business sector, federal government, nonfederal government, higher education institutions, and other nonprofit organizations. At numerous points, the chapter directly contrasts these U.S. R&D indicators with broadly comparable data from the world's other major economies.

Chapter Organization

This chapter is organized into four principal sections on the following discussion topics: the recent trends (particularly over the last 5–10 years) in overall U.S. R&D performance, comparison of U.S. R&D performance to that of other leading countries, the U.S. business sector's large role in the nation's overall R&D activity, and the federal government's roles in supporting and conducting U.S. R&D.

Recent Trends in U.S. R&D Performance

The U.S. R&D system consists of the R&D activities of a variety of performers and sources of funding. Included here are private businesses, the federal government, nonfederal government, higher education (universities and colleges), and other nonprofit organizations. The organizations that perform R&D often receive significant levels of outside funding; furthermore, those that fund R&D may also themselves be significant performers. This section discusses the current levels and notable recent trends in overall U.S. R&D performance and the sources funding these activities. (Definitions for key terms in this section appear in this chapter's Glossary. The sidebar Measured and Unmeasured R&D discusses the main data sources for the indicators and analyses in this section of the chapter. In addition to the data presented in this section's figures and tables, National Center of Science and Engineering Statistics [NCSES] statistics on U.S. R&D performance go back to 1953; this historical time series can be found in Appendix Table 4-1 through Appendix Table 4-9.)

SIDEBAR

Measured and Unmeasured R&D

The statistics on U.S. R&D discussed in this section reflect the periodic *National Patterns of R&D Resources* reports from the National Center of Science and Engineering Statistics (NCSES) within the National Science Foundation (NSF), which provide a comprehensive account of total U.S. R&D performance. The *National Patterns* data, in turn, derive from six major NCSES surveys of the organizations that perform or fund the bulk of U.S. R&D:

- Business R&D and Innovation Survey
- Higher Education Research and Development Survey
- Survey of Federal Funds for Research and Development
- Federally Funded Research and Development Center R&D Survey
- Survey of State Government Research and Development
- Survey of Research and Development Funding and Performance by Nonprofit Organizations

The *National Patterns* analysis integrates R&D spending and funding data from these separate surveys into U.S. R&D performance totals, which are then reported on a calendar year basis and for the main performing sectors and funding sources.

Because of practical constraints in the surveys, some elements of R&D performance are omitted from the U.S. totals. In evaluating R&D performance trends over time and in international comparisons, it is important to be aware of these omissions.

The U.S. business R&D estimates are derived from a survey of R&D-performing companies with five or more employees. No estimates of R&D performance currently are available for companies with fewer than five employees. Nonetheless, NCSES survey development efforts have been underway over the last several years such that R&D data on this micro business population are expected to be available in the future.

The statistics for academic R&D track expenditures that are separately accounted for in both sponsored research and institutionally funded research. U.S. universities do not report funds for research that are not separately accounted for, such as estimates of faculty time spent on research beyond formally tracked research projects. This can be a limitation in international R&D comparisons because such estimates are often included in the national statistics of other countries.

Likewise, the activity of individuals performing R&D on their own time and not under the auspices of a corporation, university, or other organization is omitted from official U.S. R&D statistics.

Statistics on R&D performed by state governments are collected in an annual NCSES and U.S. Census Bureau survey. Although these data represent small amounts (typically totaling only several hundred million dollars annually), they are now included in the *National Patterns* totals. Estimates for the R&D performed in the U.S. by nonprofit organizations remain based on parameters in NSF's 1996–97 survey of this sector. A pilot test for a new and expanded nonprofit R&D survey has recently been completed; a full fielding of the new survey is now anticipated in 2018.

U.S. Total R&D and R&D Intensity

The most recent NCSES data indicate that R&D performed in the United States totaled $495.1 billion in 2015 (Table 4-1; Figure 4-1). The corresponding total for 2014 was $475.4 billion. These numbers compare to U.S. R&D totals of $433.6 billion in 2012 and $454.0 billion in 2013. In 2008—just before the onset of the main economic effects of the national and international financial crisis and the Great Recession—the U.S. total was $404.8 billion. (All amounts and calculations are in current dollars, unless otherwise noted.)

TABLE 4-1

U.S. R&D expenditures, by performing sector and source of funds: 2008–15

(Millions of current and constant 2009 dollars)

Sector	2008	2009	2010	2011	2012	2013	2014	2015[a]
Current $millions								
All performing sectors	404,773	402,931	406,580	426,160	433,619	453,964	475,426	495,144
Business	290,680	282,393	278,977	294,092	302,251	322,528	340,728	355,821
Federal government	45,649	47,572	50,798	53,524	52,144	51,086	52,687	54,322
Federal intramural[b]	29,839	30,560	31,970	34,950	34,017	33,406	34,783	35,673
FFRDCs	15,810	17,013	18,828	18,574	18,128	17,680	17,903	18,649
Nonfederal government	491	606	691	694	665	620	583	610
Higher education	52,054	54,909	58,084	60,089	60,896	61,546	62,354	64,653
Other nonprofit organizations[c]	15,898	17,452	18,030	17,762	17,663	18,185	19,075	19,738
All funding sources	404,773	402,931	406,580	426,160	433,619	453,964	475,426	495,144
Business	258,016	246,610	248,124	266,421	275,717	297,167	318,382	333,207
Federal government	117,615	125,765	126,617	127,015	123,838	120,130	118,363	120,933
Nonfederal government	4,221	4,295	4,302	4,386	4,158	4,244	4,214	4,280
Higher education	11,738	12,056	12,262	13,104	14,300	15,378	16,217	17,334
Other nonprofit organizations[c]	13,184	14,205	15,275	15,235	15,607	17,045	18,250	19,390
Constant 2009 $millions								
All performing sectors	407,848	402,931	401,673	412,503	412,127	424,610	436,844	450,080
Business	292,888	282,393	275,610	284,667	287,271	301,673	313,077	323,437
Federal government	45,995	47,572	50,185	51,809	49,560	47,783	48,411	49,378
Federal intramural[b]	30,066	30,560	31,584	33,830	32,331	31,246	31,961	32,427
FFRDCs	15,930	17,013	18,601	17,978	17,229	16,537	16,451	16,951
Nonfederal government	495	606	683	672	632	580	536	555
Higher education	52,450	54,909	57,383	58,163	57,877	57,566	57,293	58,768
Other nonprofit organizations[c]	16,019	17,452	17,812	17,193	16,788	17,009	17,527	17,942
All funding sources	407,848	402,931	401,673	412,503	412,127	424,610	436,844	450,080

Sector	2008	2009	2010	2011	2012	2013	2014	2015[a]
Business	259,975	246,610	245,129	257,883	262,051	277,952	292,544	302,881
Federal government	118,508	125,765	125,089	122,944	117,700	112,363	108,758	109,927
Nonfederal government	4,253	4,295	4,250	4,245	3,952	3,970	3,872	3,890
Higher education	11,827	12,056	12,114	12,684	13,591	14,383	14,901	15,756
Other nonprofit organizations[c]	13,284	14,205	15,091	14,747	14,833	15,943	16,769	17,625

FFRDC = federally funded research and development center.

[a] Some data for 2015 are preliminary and may later be revised.

[b] Includes expenditures of federal intramural R&D, as well as costs associated with administering extramural R&D.

[c] Some components of the R&D performed by other nonprofit organizations are projected and may later be revised.

Note(s)

Data are based on annual reports by performers, except for the nonprofit sector. Expenditure levels for higher education, federal government, and nonfederal government performers are calendar-year approximations based on fiscal year data.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Patterns of R&D Resources (annual series).

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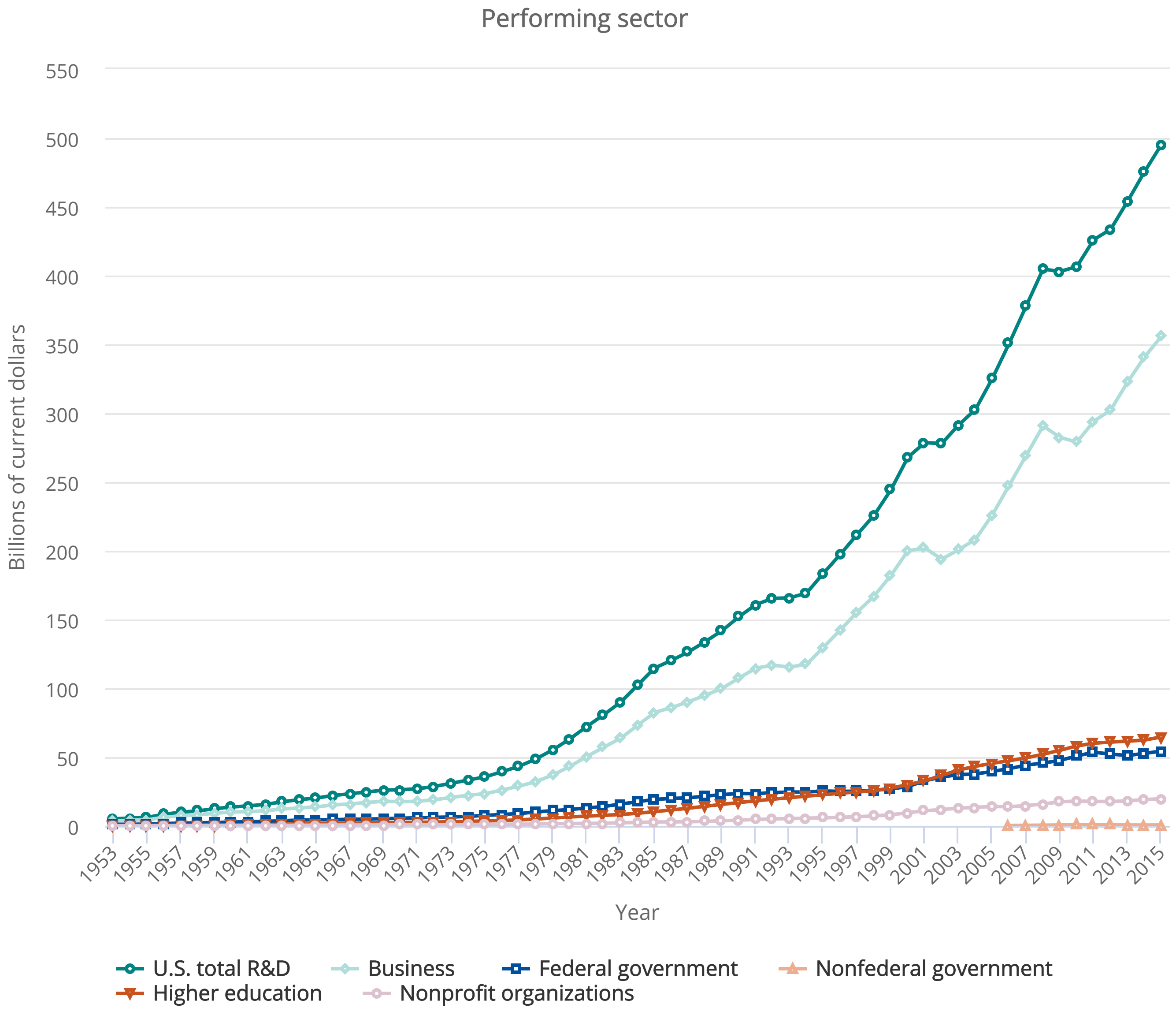
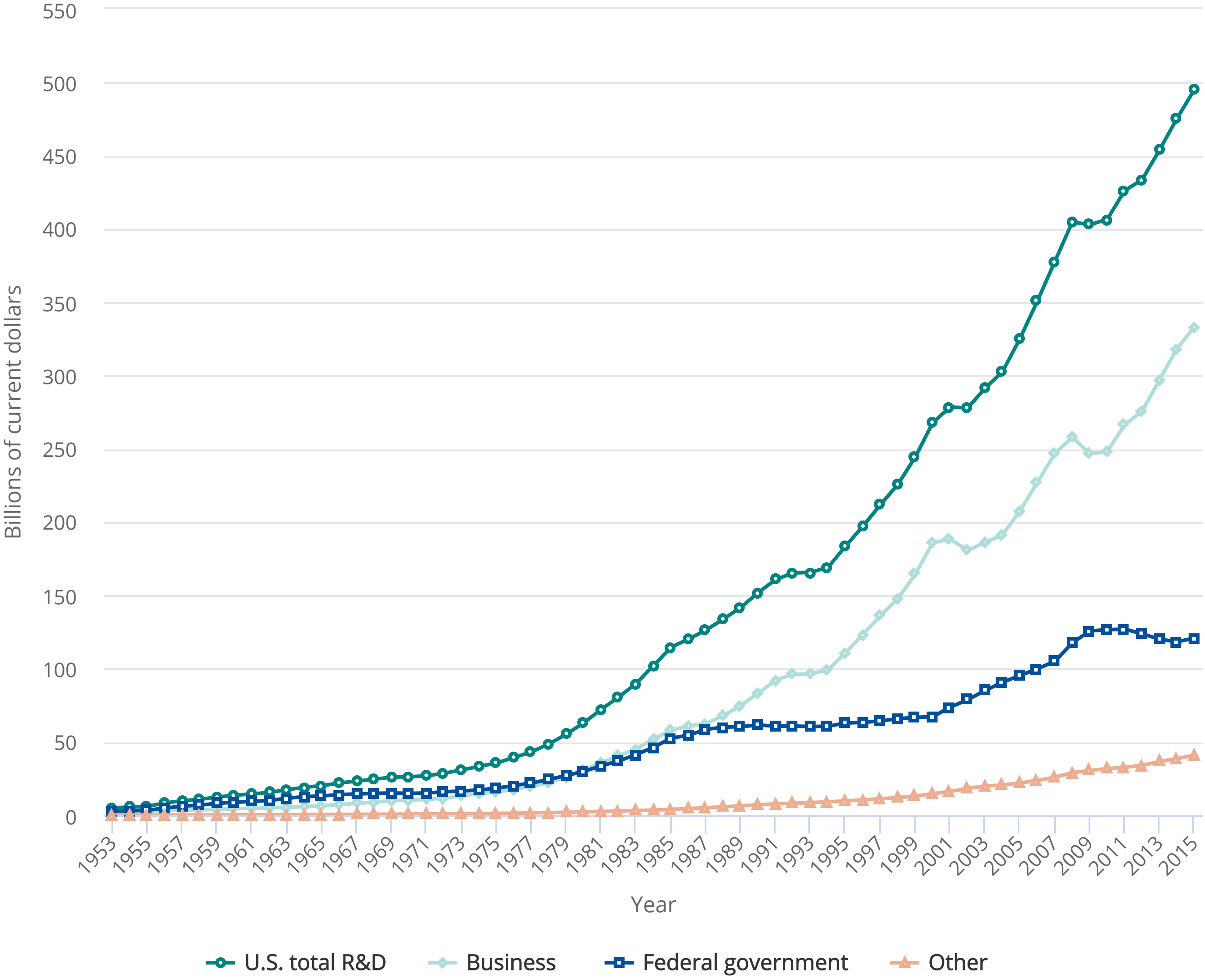
FIGURE 4-1

U.S. R&D, by performing sector and source of funds: 1953–2015



Source of funds



Note(s)

Some data for 2015 are preliminary and may later be revised. Some components of the R&D performed by other nonprofit organizations are projected and may later be revised. Federal performers of R&D include federal agencies and federally funded R&D centers. Performance by nonfederal government includes mainly state and local governments (data in this series are not available before 2006). Other funding includes support from higher education, nonfederal government, and nonprofit organizations.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Patterns of R&D Resources (annual series).

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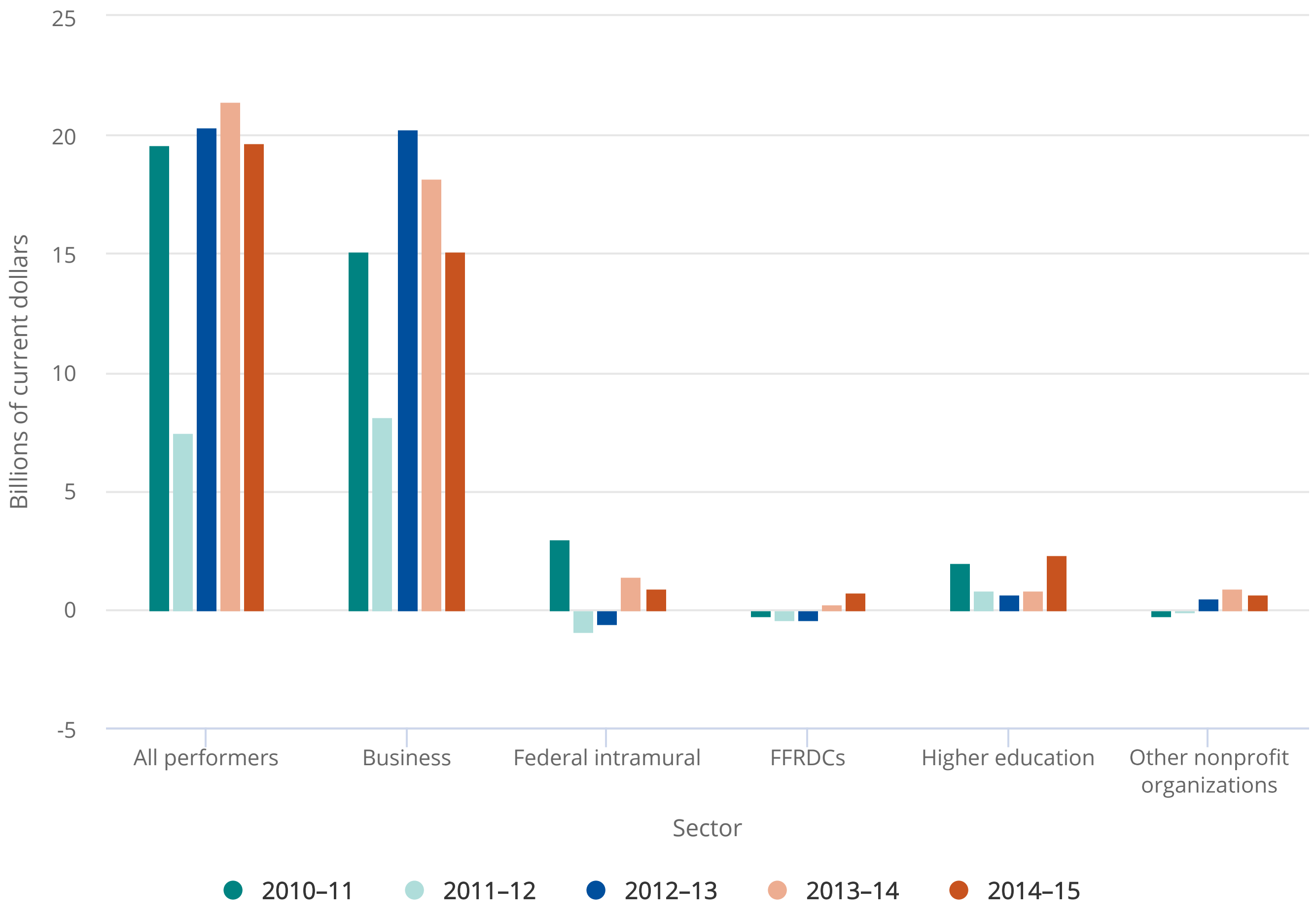
These data reflect increases of $21.5 billion in 2014 and $19.7 billion in 2015—year-over-year increases in the U.S. total from 2010 to 2015 averaged $17.7 billion. The 2014 and 2015 increases reflect mainly higher levels of business R&D

performance (Figure 4-2). Across the other main R&D-performing sectors, the annual changes were far smaller—and in some cases, were declines.

FIGURE 4-2

Year-to-year changes in U.S. R&D expenditures, by performing sector: 2010–15



FFRDC = federally funded research and development center.

Note(s)

Data are calculated from R&D expenditure data reported for performers in Table 4-1. Expenditures by nonfederal government performers are comparatively negligible, and specific bars for this sector are excluded.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Patterns of R&D Resources (annual series).

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Adjusted for inflation, growth in U.S. total R&D averaged 1.4% annually over the 7-year period of 2008–15, marginally behind the 1.5% average pace of U.S. gross domestic product (GDP) (Table 4-2).[1] By comparison, the average annual rate of growth was notably higher in the prior 10-year period (1998–2008): 3.6% for total R&D and 2.2% for GDP. (As a comparative yardstick, a 7% average annual rate of growth yields a doubling of the quantity in 10 years.)

In part, the smaller average annual rate of growth for the 2008–15 period (by contrast to 1998–2008) partly reflects the inclusion of the Great Recession years (notably, 2009 and 2010) at the outset of this period. Considering just the 5-year period of 2010–15, the average annual pace of growth for U.S. R&D is 2.3%, compared to 2.2% for GDP (Table 4-2). The growth of business R&D over this same 5-year period is 3.3%, well ahead of GDP growth, but it is not strong enough to offset the slower average rates of growth (if not outright declines) in some of the other performing sectors.

TABLE 4-2

Annual rates of growth in U.S. R&D expenditures, total and by performing sectors: 1988–2015

(Percent)

Expenditures and gross domestic product	Longer-term trends			Most recent years						
	1988–98	1998–2008	2008–15	2008–09	2009–10	2010–11	2011–12	2012–13	2013–14	2014–15
Current $										
Total R&D, all performers	5.4	6.0	2.9	-0.5	0.9	4.8	1.8	4.7	4.7	4.1
Business	5.8	5.7	2.9	-2.9	-1.2	5.4	2.8	6.7	5.6	4.4
Federal government	1.8	5.9	2.5	4.2	6.8	5.4	-2.6	-2.0	3.1	3.1
Federal intramural[a]	1.9	5.6	2.6	2.4	4.6	9.3	-2.7	-1.8	4.1	2.6
FFRDCs	1.6	6.4	2.4	7.6	10.7	-1.4	-2.4	-2.5	1.3	4.2
Nonfederal government[b]	NA	NA	3.1	NA	14.1	0.4	-4.2	-6.8	-5.9	4.6
Higher education	6.0	7.4	3.1	5.5	5.8	3.5	1.3	1.1	1.3	3.7
Other nonprofit organizations[c]	8.5	8.2	3.1	9.8	3.3	-1.5	-0.6	3.0	4.9	3.5
Gross domestic product	5.6	4.9	3.0	-2.0	3.8	3.7	4.1	3.3	4.4	4.0
Constant 2009$										
Total R&D, all performers	2.9	3.6	1.4	-1.2	-0.3	2.7	-0.1	3.0	2.9	3.0
Business	3.3	3.3	1.4	-3.6	-2.4	3.3	0.9	5.0	3.8	3.3
Federal government	-0.6	3.4	1.0	3.4	5.5	3.2	-4.3	-3.6	1.3	2.0
Federal intramural[a]	-0.5	3.2	1.1	1.6	3.4	7.1	-4.4	-3.4	2.3	1.5
FFRDCs	-0.8	4.0	0.9	6.8	9.3	-3.3	-4.2	-4.0	-0.5	3.0
Nonfederal government[b]	NA	NA	1.6	NA	12.7	-1.6	-5.9	-8.3	-7.5	3.5
Higher education	3.5	4.9	1.6	4.7	4.5	1.4	-0.5	-0.5	-0.5	2.6
Other nonprofit organizations[c]	5.9	5.7	1.6	8.9	2.1	-3.5	-2.4	1.3	3.0	2.4
Gross domestic product	3.4	2.2	1.5	-2.8	2.5	1.6	2.2	1.7	2.6	2.9

NA = not available.

FFRDC = federally funded research and development center.

[a] Includes expenditures of federal intramural R&D, as well as costs associated with administering extramural R&D.

[b] Survey data on state internal R&D performance were not available prior to 2006.

[c] Some components of the R&D performed by other nonprofit organizations are projected and may later be revised.

Note(s)

Longer-term trend rates are calculated as compound annual growth rates. Data for 2015 are preliminary and may later be revised.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Patterns of R&D Resources (annual series).

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Regarding the intensity of R&D in the national economy, the ratio of U.S. R&D expenditures to GDP was 2.73% in 2015 and also 2.73% in 2014 (Figure 4-3). In comparison, the ratio was 2.72% in 2013 and 2.68% in 2012. (The ratio of total national R&D expenditures to GDP is often reported as a measure of the intensity of a nation's overall R&D effort and is widely used as an international benchmark for comparing countries' R&D activities.)

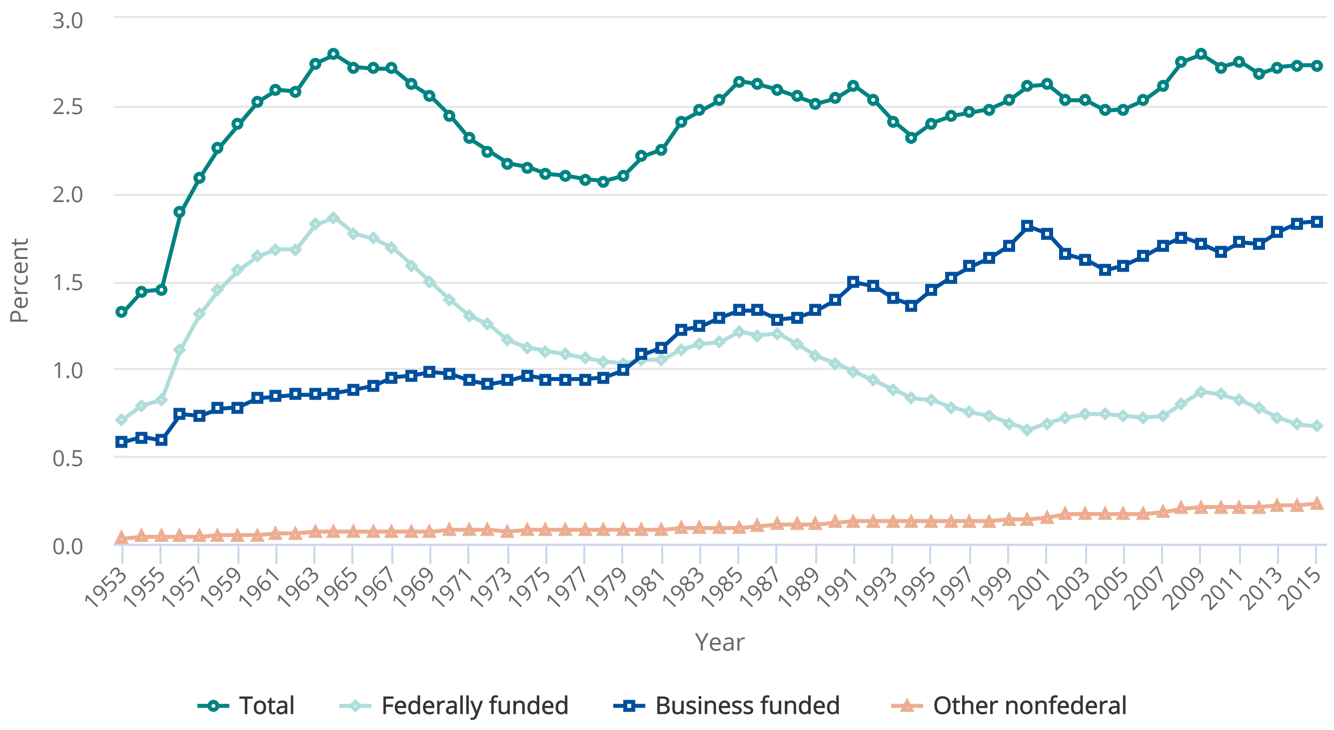
The U.S. R&D-to-GDP ratio stood at 2.79% in 2009—matching the ratio's highest level since the start of the time series in 1953 (it was also 2.79% in 1964). Over the 10-year period 2005–15, the ratio has fluctuated year to year, between a low of 2.48% in 2005 and the aforementioned high of 2.79% in 2009.

The broader trend since the late 1990s has been a rising R&D-to-GDP ratio, although with some periods of decline. Most of the rise of this ratio over the past several decades has been from the increase of nonfederal spending on R&D, particularly by the business sector. This arises from the growing role of business R&D in the national R&D system, which in turn reflects the unabated increase of R&D-dependent goods and services in the national and global economies.

By contrast, the ratio of federally funded R&D expenditures to GDP declined from the mid-1980s to the late 1990s, notably from cuts in defense-related R&D. There had been a gradual uptick in the ratio through 2009, the result of increased federal spending on biomedical and national security R&D and the one-time incremental funding for R&D provided by the American Recovery and Reinvestment Act of 2009 (ARRA). But the federally funded R&D-to-GDP ratio has returned to a path of decline since 2010 (Figure 4-3).

FIGURE 4-3

Ratio of U.S. R&D to gross domestic product, by roles of federal, business, and other nonfederal funding for R&D: 1953–2015



Note(s)

Some data for 2015 are preliminary and may later be revised. The federally funded data represent the federal government as a funder of R&D by all performers and similar for the business-funded data. The other nonfederal category includes R&D funded by all other sources—mainly, higher education, nonfederal government, and other nonprofit organizations. The gross domestic product data used reflect the U.S. Bureau of Economic Analysis's comprehensive revisions of the national income and product accounts of July 2017.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Patterns of R&D Resources (annual series).

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Of note, the Department of Commerce's Bureau of Economic Analysis (BEA) introduced a comprehensive set of revisions to the U.S. national income and product accounts in July 2013, including explicitly recognizing R&D as investment in the measure of U.S. GDP. These changes resulted in modest revisions to the U.S. GDP time series back to 1929. The R&D-to-GDP ratio data reported here reflect BEA's revised GDP data series, both in the present and the past. For further information, see sidebar R&D in the U.S. National Income and Product Accounts.

SIDEBAR

R&D in the U.S. National Income and Product Accounts

Comprehensive revision of the U.S. gross domestic product (GDP) and related national income and product accounts (NIPA), released by the Bureau of Economic Analysis (BEA) in July 2013, included a change to treat R&D as a fixed investment with long-term benefits. R&D investment is now recognized in NIPA in a new asset category called “intellectual property products,” or intangible assets, along with software and entertainment, literary, and artistic originals. Before this change, the NIPA considered R&D as an expense or intermediate input cost in the business sector and as consumption in the government and nonprofit sectors (BEA 2013). This update is one of several NIPA changes aimed at capturing the role of intangible assets in economic growth. (BEA’s comprehensive updates occur about every 5 years—the most recent of which was the aforementioned July 2013 update. However, there have also been annual updates since July 2013, each of which has affected GDP and related data for the most recent years.) The National Center for Science and Engineering Statistics (NCSES) surveys of U.S. R&D expenditures serve as the primary data source for the R&D component of these revisions. (For a further discussion, see Moris et al. [2015].)

As a part of these July 2013 revisions, BEA provided a revised time series for GDP and its components going back to 1929. After these comprehensive revisions, GDP levels are somewhat higher in this revised time series than previously reported. An implication is that the R&D-to-GDP ratios reported in past editions of *Science and Engineering Indicators* and related publications on U.S. R&D are somewhat smaller because of this higher reported GDP. For example, the U.S. R&D-to-GDP ratio for 2000, previously reported as 2.70%, is now 2.61% under the revised NIPA, or what was 2.84% in 2011 under the previous methodology is revised to 2.75%. The U.S. R&D statistics reported throughout in this chapter fully reflect BEA’s revised GDP data series from the July 2013 comprehensive update and subsequent annual updates.

Performers of R&D

NCSES tracks the R&D spending patterns of the major performers in the overall U.S. R&D system. Included are businesses, the intramural R&D activities of federal agencies, federally funded research and development centers (FFRDCs), nonfederal government organizations (mainly state government), higher education institutions, and other nonprofit organizations. (All amounts and calculations are in current dollars, unless otherwise noted.)

Business Sector

The business sector is by far the largest performer of U.S. R&D. In 2015, domestically performed business R&D accounted for $355.8 billion, or 72% of the $495.1 billion national total (Table 4-1 and Table 4-3). The business sector’s predominance in the composition of national R&D performance has long been the case, with its annual share ranging between 69% and 75% over the 20-year period of 1995–2015 (Appendix Table 4-2). Business R&D performance increased by $15.1 billion in 2015, following gains of $8.2 billion in 2012, $20.3 billion in 2013, and $18.2 billion in 2014. These increases are in contrast to the essentially unchanged levels of business R&D performance in both 2009 and 2010.[2]

TABLE 4-3

U.S. R&D expenditures, by performing sector, source of funds, and type of work: 2015

(Millions of dollars)

Performing sector and type of work	Total	Business	Federal government	Nonfederal government	Higher education	Other nonprofit organizations	Distribution by performer (%)
R&D	495,144	333,207	120,933	4,280	17,334	19,390	100.0
Business	355,821	327,589	26,990	127	*	1115	71.9
Federal government	54,322	205	53,960	19	*	138	11.0
Federal intramural	35,673	0	35,673	0	0	0	7.2
FFRDCs	18,649	205	18,287	19	*	138	3.8
Nonfederal government	610	*	249	361	*	*	0.1
Higher education	64,653	3,842	33,546	3,772	17,334	6,159	13.1
Other nonprofit organizations	19,738	1,572	6,189	*	*	11,978	4.0
Percent distribution by funding source	100.0	67.3	24.4	0.9	3.5	3.9	-
Basic research	83,462	22,717	36,946	2,354	10,880	10,565	100.0
Business	21,792	19,621	2,038	14	*	120	26.1
Federal government	10,053	47	9,969	4	*	32	12.0
Federal intramural	5,926	0	5,926	0	0	0	7.1
FFRDCs	4,127	47	4,043	4	*	32	4.9
Nonfederal government	100.5	*	41.0	59.5	*	*	0.1
Higher education	40,983	2,176	21,888	2,277	10,880	3,763	49.1
Other nonprofit organizations	10,534	873	3,010	*	*	6,651	12.6
Percent distribution by funding source	100.0	27.2	44.3	2.8	13.0	12.7	-

Performing sector and type of work	Total	Business	Federal government	Nonfederal government	Higher education	Other nonprofit organizations	Distribution by performer (%)
Applied research	97,150	51,738	34,511	1,419	4,567	4,917	100.0
Business	56,472	50,137	6,102	24	*	209	58.1
Federal government	16,551	96	16,382	9	*	64	17.0
Federal intramural	9,200	0	9,200	0	0	0	9.5
FFRDCs	7,351	96	7,182	9	*	64	7.6
Nonfederal government	496.0	*	202.2	293.8	*	*	0.5
Higher education	17,466	1,107	9,094	1,092	4,567	1,608	18.0
Other nonprofit organizations	6,165	398	2,731	*	*	3,036	6.3
Percent distribution by funding source	100.0	53.3	35.5	1.5	4.7	5.1	-
Experimental development	314,532	258,753	49,476	507	1,888	3,908	100.0
Business	277,557	257,831	18,850	90	*	786	88.2
Federal government	27,718	62	27,609	6	*	42	8.8
Federal intramural	20,547	0	20,547	0	0	0	6.5
FFRDCs	7,171	62	7,062	6	*	42	2.3
Nonfederal government	13.6	*	5.5	8.0	*	*	0.0
Higher education	6,204	560	2,565	404	1,888	789	2.0
Other nonprofit organizations	3,040	301	447	*	*	2,292	1.0

Performing sector and type of work	Total	Business	Federal government	Nonfederal government	Higher education	Other nonprofit organizations	Distribution by performer (%)
Percent distribution by funding source	100.0	82.3	15.7	0.2	0.6	1.2	-

* = small to negligible amount, included as part of the funding provided by other sectors; NA = not available.

FFRDC = federally funded research and development center.

Note(s)

Data for 2015 include some estimates and may later be revised. Some components of R&D performance and funding by other nonprofit organizations are projected and may later be revised.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Patterns of R&D Resources (annual series).

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Inflation-adjusted growth in business R&D averaged 1.4% annually over the 7-year period 2008–15, essentially at the 1.4% annual average for total R&D and just behind the 1.5% annual average for GDP (Table 4-2). Nonetheless, growth in business R&D substantially surpassed the growth rates for both total R&D and GDP in 4 of the 7 years spanning the full 2008–15 period (2011, 2013, 2014, and 2015).

Higher Education

The higher education sector is the second largest performer of U.S. R&D. Universities and colleges performed $64.7 billion, or 13%, of U.S. R&D in 2015 (Table 4-1 and Table 4-3).[3] Over the 20-year period 1995–2015, the higher education share of U.S. R&D has ranged between 11% and 14% (Appendix Table 4-2). Furthermore, the higher education sector is a special niche in the nation's overall R&D system: in recent years it has accounted for just under half of the nation's basic research, while training the nation's next generation of researchers. (For statistics, see section R&D, by Type of Work later in this chapter.)

Higher education R&D performance increased by $2 billion–$3 billion each year over 2009–11; however, the annual increases dropped below $1 billion in 2012–14 (Table 4-1). The data show a $2 billion increase in 2015. After adjusting for inflation, growth in this sector's R&D performance averaged 1.6% annually over 2008–15, somewhat ahead of that for U.S. total R&D (1.4%) and GDP (1.5%). However, when the year-by-year track is examined, the sector's growth was stronger in the first half of this period (2009, 2010, and 2011) (Table 4-2).

Federal Agencies and Federally Funded Research and Development Centers

The federal government conducted $54.3 billion, or 11%, of U.S. R&D in 2015 (Table 4-1 and Table 4-3). This included $35.7 billion (7% of the U.S. total) for intramural R&D performed by federal agencies in their own research facilities and $18.6 billion (4%) of R&D performed by the 41 FFRDCs.[4] (FFRDCs are R&D-performing organizations that are exclusively or substantially financed by the federal government. An FFRDC is operated to provide R&D capability to serve agency mission objectives or, in some cases, to provide major facilities at universities for research and associated training purposes. Each

FFRDC is administered by an industrial firm, a university, a nonprofit institution, or a consortium.[5]) In 1995, the federal performance share of U.S R&D was about 14%, but it has gradually declined—although with some occasional increases—in the years since.

The federal performance total increased by $2 to $3 billion each year over 2009–11. But it decreased $1.4 billion in 2012 and $1.1 billion in 2013. In 2014, there was a $1.6 billion increase and about the same in 2015. These changes affected both federal intramural R&D and FFRDCs (Table 4-1). Adjusted for inflation, growth in this sector's R&D performance averaged 1.0% annually over 2008–15, behind that for U.S. total R&D (1.4%) and GDP (1.5%). The reversal in the 2012–15 period of the expansionary trend seen during 2009–11 reflects both the waning after 2010 of the incremental funding from ARRA and the more recent federal budget environment after 2011.

This volume of the federal government's R&D performance is small compared with that of the U.S. business sector. Even so, the $54.3 billion performance total in 2015 exceeded the total national R&D expenditures of every country except China, Japan, Germany, South Korea, and France.[6]

Other Nonprofit Organizations and Nonfederal Government

R&D performed in the United States by other nonprofit organizations (which excludes universities and FFRDCs) was $19.7 billion in 2015 (Table 4-1 and Table 4-3). This was 4% of U.S. total R&D in 2015, a share that has increased only slightly since the late 1990s.

NCSES started to track the annual intramural R&D performance of state agencies in 2006. The total for all 50 states and the District of Columbia in 2015 is estimated to be $610 million—a small share (about 0.1%) of the U.S. total (Table 4-1 and Table 4-3).

Geographic Location of R&D

The sidebar Location of R&D Performance, by State summarizes the leading geographic locations of U.S. R&D performance. For additional R&D indicators at the state level, see the State Indicators data tool.

SIDEBAR

Location of R&D Performance, by State

Distribution of R&D expenditures among the U.S. states

In 2015, the 10 states with the largest R&D expenditure levels accounted for about 65% of U.S. R&D expenditures that can be allocated to the states: California, Massachusetts, Texas, New York, Maryland, Michigan, Washington, Illinois, New Jersey, and Pennsylvania (Table 4-A; Appendix Table 4-10).* California alone accounted for 25% of the U.S. total, about four times as much as Massachusetts, the next highest state. The top 20 states accounted for 85% of the R&D total; the 20 lowest-ranking states accounted for around 4% (Appendix Table 4-11).

The states with the largest R&D expenditures are not necessarily those with the highest intensity of R&D. Among those with the greatest R&D-to-GDP ratios in 2015 were New Mexico, Massachusetts, Maryland, California, and Washington (Table 4-A). New Mexico is the location of several major government research facilities. Massachusetts benefits from both leading research universities and thriving high-technology industries. Maryland is the site of many government research facilities and growing research universities. California has relatively high R&D intensity and benefits from the presence of Silicon Valley, other high-technology industries, federal R&D, and leading research universities, but it is still fourth on this list. Washington State is home to government research facilities, leading research universities, and high-technology industries.

U.S. R&D performance, by sector and state

The proportion of R&D performed by each of the main R&D-performing sectors (business, higher education, federal intramural R&D facilities, and federally funded R&D centers [FFRDCs]) varies across the states. But the states that lead in total R&D also tend to be well represented in each of these sectors (Table 4-A).

In 2015, R&D performed by the business sector accounted for about 73% of the U.S. total R&D that could be allocated to specific states. Of the top 10 states in total R&D performance, 9 states are also in the top 10 in business R&D. Connecticut, 10th in business sector R&D, surpasses Maryland in the business R&D ranking.

Higher education-performed R&D accounts for 15% of the allocable U.S. total. The top 10 states for higher education R&D performance include 7 that are also top 10 in total R&D performance. But Connecticut, New Jersey, and Washington fall out and are replaced by Florida, Maryland, and North Carolina.

Federal R&D performance (including both intramural R&D facilities and FFRDCs)—about 10% of the U.S. total—is more concentrated geographically than other sectors. Only five jurisdictions—Maryland, California, New Mexico, Virginia, and the District of Columbia—account for 63% of all federal R&D performance.† This figure rises to 80% when the other 5 of the top 10 state locations for federal R&D performance—Massachusetts, Alabama, Tennessee, Washington, and Illinois—are included.

Federal R&D accounts for the bulk of total R&D in several states, including New Mexico (85%), which is home to the nation's two largest FFRDCs (Los Alamos and Sandia National Laboratories), and Tennessee (35%), which is home to Oak Ridge National Laboratory. The high figures for Maryland (55%), the District of Columbia (67%), and Virginia (41%) reflect the concentration of federal facilities and federal R&D administrative offices in the national capital area.

TABLE 4-A

Top 10 states in U.S. R&D performance, by sector and intensity: 2015

(Millions of current dollars, ranking, and R&D-to-GDP ratio)

Rank	All R&D[a]		Sector ranking			R&D intensity (R&D-to-GDP ratio)		
	State	Amount (current $millions)	Business	Higher education	Federal intramural and FFRDCs[b]	State	R&D/ GDP (%)	GDP (current $billions)
1	California	125,056	California	California	Maryland	New Mexico	6.52	93.2
2	Massachusetts	28,665	Massachusetts	New York	California	Massachusetts	5.87	488.1
3	Texas	23,668	Michigan	Texas	New Mexico	Maryland	5.57	366.2
4	New York	22,401	Texas	Maryland	Virginia	California	5.02	2,491.6
5	Maryland	20,385	Washington	Massachusetts	District of Columbia	Washington	4.49	446.4
6	Michigan	19,891	New York	Pennsylvania	Massachusetts	Michigan	4.23	470.6
7	Washington	20,038	New Jersey	North Carolina	Alabama	Delaware	4.19	68.9
8	Illinois	16,502	Illinois	Illinois	Tennessee	Connecticut	3.87	256.3
9	New Jersey	15,865	Pennsylvania	Florida	Illinois	Idaho	3.34	72.6
10	Pennsylvania	14,839	Connecticut	Michigan	Washington	Oregon	3.38	215.3

FFRDC = federally funded research and development center; GDP = gross domestic product.

[a] Includes in-state total R&D performance of the business sector, universities and colleges, federal agencies, FFRDCs, and federally financed nonprofit R&D.

[b] Includes costs associated with administration of intramural and extramural programs by federal personnel and actual intramural R&D performance.

Note(s)

Small differences in parameters for state rankings may not be significant. Rankings do not account for the margin of error of the estimates from sample surveys.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Patterns of R&D Resources (annual series). State GDP data are from the U.S. Bureau of Economic Analysis. See Appendix Table 4-10.

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* The latest data available on the distribution of U.S. R&D performance by state are for 2015 (Appendix Table 4-10). Total U.S. R&D expenditures that year are estimated at $495.1 billion. Of this total, $468.9 billion could be attributed to one of the 50 states or the District of Columbia. This state-attributed total differs from the U.S. total for several reasons: Some business R&D expenditures cannot be allocated to any of the 50 states or the District of Columbia because respondents did not answer the question related to location, nonfederal sources of nonprofit R&D expenditures (about $11 billion in 2015) could not be allocated by state, state-level university R&D data have not been adjusted for double-counting of R&D passed from one academic institution to other performers, and state-level university and federal R&D performance data are not converted from fiscal to calendar years.

† Federal intramural R&D includes costs associated with the administration of intramural and extramural programs by federal personnel, as well as actual intramural R&D performance. This is a main reason for the large amount of federal intramural R&D in the District of Columbia.

Sources of R&D Funding

Funds that support the conduct of R&D in the United States come from a variety of sources, including businesses, federal and nonfederal government agencies, higher education institutions, and other nonprofit organizations. For the most part, the mix of funding sources varies by performer. (All amounts and calculations are in current dollars, unless otherwise noted.)

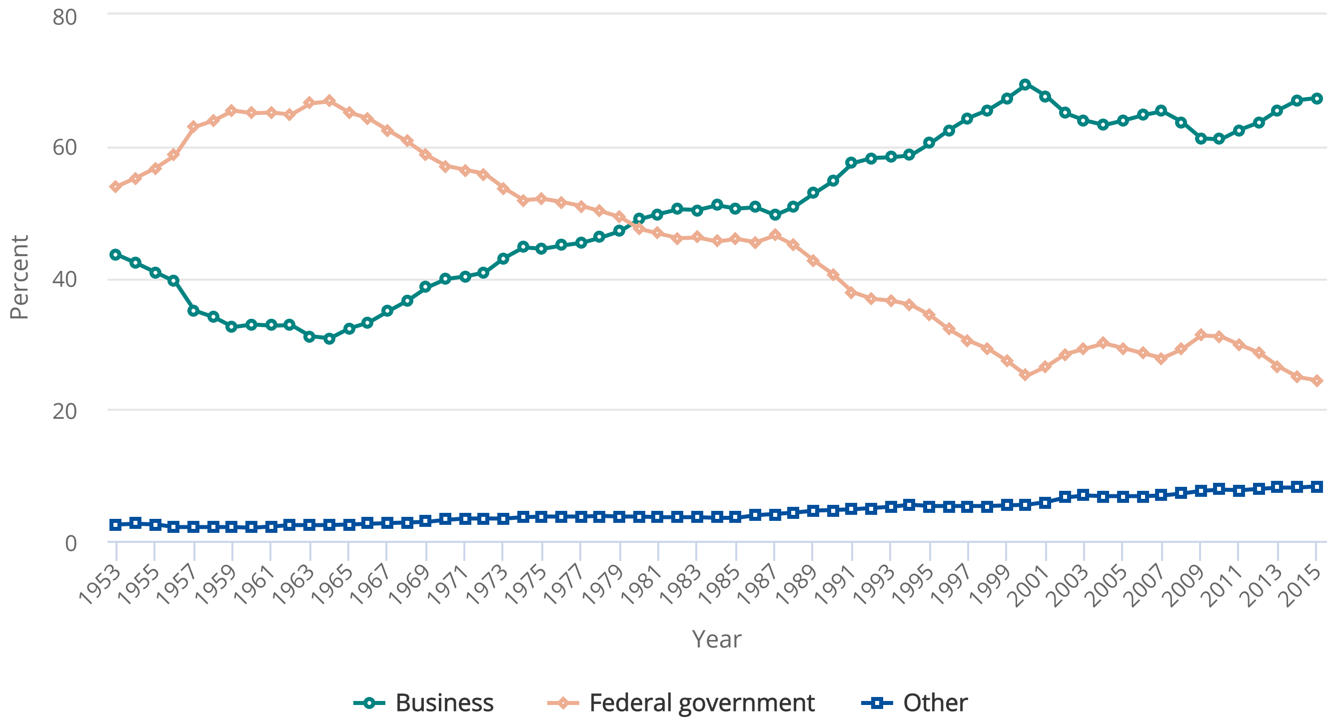
R&D Funding by Business

The business sector is the predominant source of funding for R&D performed in the United States. In 2015, business sector funding accounted for $333.2 billion, or 67%, of the $495.1 billion of total U.S. R&D performance (Table 4-1 and Table 4-3). Nearly all (98%) of the business sector's funding for R&D that year was directed at business R&D performance—even if funding provided by some businesses was performed by other businesses.[7] The small remainder went to R&D performers in higher education, other nonprofit organizations, and FFRDCs.

The business sector's large role in the nation's R&D funding began in the early 1980s, when the support it provided started to exceed 50% of all U.S. R&D funding (Figure 4-4). This business share moved up to 60% in 1995. It has been above that level throughout the years since, but fluctuating in the range of 60%–69% (Appendix Table 4-6).

FIGURE 4-4

U.S. total R&D expenditures, by source of funds: 1953–2015



Note(s)

Data for 2015 are preliminary and may later be revised. The other category includes nonfederal government, higher education, and other nonprofit organizations.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Patterns of R&D Resources (annual series).

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R&D Funding by the Federal Government

The federal government is the second largest source of overall funding for U.S. R&D. It is a major source for most U.S. R&D performer sectors except business, where the federal role, although not negligible, is overshadowed by the business sector's own funds.

Funds from the federal government accounted for $120.9 billion, or 24%, of U.S. total R&D in 2015 (Table 4-1 and Table 4-3). This federal funding was directed mainly to R&D performance by the federal government, business, and higher education.

Federal funding accounted for all of the $35.7 billion of federal intramural R&D performance in 2015 and most (98%) of the $18.6 billion of R&D performed by FFRDCs. Nonfederal support for FFRDC R&D has been around $0.4 billion or so in recent years, or 2% of FFRDCs' total support.

Federal funding to the business sector accounted for $27.0 billion of business R&D performance in 2015, or 8% of the sector's R&D total that year (Table 4-3). Federal funds to higher education supported $33.5 billion, or 52%, of the $64.7 billion spent on academic R&D in 2015. For the R&D performed by other nonprofit organizations, $6.2 billion (31%) of this sector's $19.7 billion of performance was supported by federal funds.

The federal government was once the leading sponsor of the nation's R&D, funding some 67% of all U.S. R&D in 1964 (Figure 4-4). The federal share decreased in subsequent years to 49% in 1979, 36% in 1994, down to a historical low of 25% in 2000. However, changing business conditions and expanded federal funding for health, defense, and counterterrorism R&D (including that from the ARRA) pushed the federal funding share to 31% in 2009 and 2010. But the federal share has declined somewhat in the subsequent years, falling to 24% in 2015, reflecting the waning after 2010 of the incremental funding from the ARRA and the more recent federal budget environment since 2011.

Through the early 1960s, the federal government had funded more than half of the nation's business-performed R&D. However, this share declined in subsequent years to around 9% in 2000, increasing again to 12%–14% from 2008 to 2010, but dropping back down to 8% by 2015 (Appendix Table 4-2).

R&D Funding from Other Sources

The remainder of R&D funding from other sources is a smaller component: $41.0 billion in 2015, or about 8% of all U.S. R&D performance (Table 4-3). Of this amount, $17.3 billion (4%) was from higher education's own institutional funds, all of which remain in the academic sector; $4.3 billion (1%) was from state and local governments, primarily supporting academic research; and $19.4 billion (4%) was from other nonprofit organizations, the majority of which funds this sector's own R&D. Of the nonprofit total, some funds ($6.2 billion) support R&D in higher education, and small amounts support business ($1.1 billion) and FFRDC ($0.1 billion) R&D performance.

R&D, by Type of Work

Basic research activities accounted for $83.5 billion, or 17% of the total of U.S. R&D expenditures in 2015 (Table 4-3 and Table 4-4). Applied research was $97.2 billion, or 20% of the total. Most of the R&D total—$314.5 billion, or 64%—went toward experimental development. (For definitions of these terms, see this chapter's Glossary. All amounts and calculations are in current dollars, unless otherwise noted.)

TABLE 4-4

U.S. R&D expenditures by type of work: Selected years, 1970–2015

(Billions of current and constant 2009 dollars; percent distribution)

Type of work	1970	1980	1990	2000	2010	2011	2012	2013	2014	2015[a]
Current $billions										
All R&D	26.3	63.2	152.0	267.9	406.6	426.2	433.6	454.0	475.4	495.1
Basic research	3.6	8.7	23.0	42.0	75.9	73.0	73.3	78.5	82.1	83.5
Applied research	5.8	13.7	34.9	56.5	79.3	82.1	87.1	88.3	91.9	97.2
Experimental development	16.9	40.7	94.1	169.4	251.4	271.0	273.3	287.1	301.5	314.5
Constant 2009 $billions										
All R&D	115.3	142.5	227.6	327.2	401.7	412.5	412.1	424.6	436.8	450.1
Basic research	15.8	19.7	34.5	51.3	75.0	70.7	69.7	73.4	75.4	75.9
Applied research	25.2	30.9	52.3	69.0	78.3	79.5	82.8	82.6	84.4	88.3
Experimental development	74.3	91.8	140.9	206.9	248.4	262.3	259.7	268.6	277.0	285.9
Percent distribution										
All R&D	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Basic research	13.7	13.8	15.2	15.7	18.7	17.1	16.9	17.3	17.3	16.9
Applied research	21.9	21.7	23.0	21.1	19.5	19.3	20.1	19.5	19.3	19.6
Experimental development	64.4	64.5	61.9	63.2	61.8	63.6	63.0	63.3	63.4	63.5

[a] Some data for 2015 are preliminary and may later be revised.

Note(s)

Detail may not add to total because of rounding. Data throughout the time series reported here are consistently based on the Organisation for Economic Co-operation and Development's Frascati Manual definitions for basic research, applied research, and experimental development. For 2010 and subsequent years, however, some changes have been introduced in the questionnaires of the sectoral expenditure surveys to improve the accuracy of respondents' classification of their R&D. Therefore, small percentage changes may not be meaningful when comparing data before 2010 with more recent data.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Patterns of R&D Resources (annual series).

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R&D encompasses a wide range of activities, from research yielding fundamental knowledge in the physical, life, and social sciences, and research addressing national defense needs and such critical societal issues as global climate change, energy efficiency, and health care to the development of platform or general-purpose technologies that can enable the creation and commercial application of new and improved goods and services. The most widely applied classification of these activities characterizes R&D as "basic research," "applied research," or "experimental development" (NSF 2006; OECD 2015; OMB 2017). (For definitions of these terms, see Glossary.)

This longstanding trio of categories has been criticized over the years as reinforcing the idea that creating new knowledge, invention, and innovation are linear processes beginning with basic research, followed by applied research and then development, and ending with the production and diffusion of new technologies and eventually commercially significant innovations. Nonetheless, alternative classifications that provide measurable distinctions, capture major differences in types of R&D, and are widely accepted as superior have yet to be developed. Despite the recognized limitations of the basic research-applied research-development classification framework, it remains useful in providing indications of differences in the motivation, expected time horizons, outputs, and types of investments associated with R&D projects.

Basic Research

Higher education institutions continued to be the primary performers of U.S. basic research in 2015, accounting for just under half (49%) of the $83.5 billion of basic research performance that year (▦Table 4-3). The business sector was the second largest basic research performer, about 26%. The federal government (agency intramural laboratories and FFRDCs) performed 12%, and other nonprofit organizations performed 13%.

The federal government remains the largest source of funding for basic research, accounting for about 44% of the $83.5 billion funding total in 2015 (▦Table 4-3). The business sector was also a substantial funder, providing 27% of the total.

Applied Research

The business sector performed 58% of the $97.2 billion of applied research in 2015 (▦Table 4-3). Higher education accounted for 18%, the federal government (federal agency intramural laboratories and FFRDCs) accounted for 17%, and nonprofit organizations accounted for 6% of applied research.

The business sector provided 53% of the funding for applied research in 2015, with the majority remaining within the sector (▦Table 4-3). The federal government accounted for about 36%, spread broadly across the performers, with the largest amounts going to higher education and federal intramural laboratories and FFRDCs.

Experimental Development

The business sector predominates in experimental development, performing 88% of the $314.5 billion the United States devoted to this R&D category in 2015 (▦Table 4-3).[8] The federal government (agency intramural laboratories, FFRDCs) accounted for another 9%—much of it defense related, with the federal government being the main consumer. By contrast, higher education and other nonprofit organizations perform relatively little development (respectively, 2% and 1% of the total in 2015).

The business sector provided 82% of the funding for the $314.5 billion of U.S. development in 2015, most of which remained in the sector (▦Table 4-3). Federal funding accounted for about 16% of the development total—with the business sector (especially defense-related industries) and federal intramural laboratories being the largest recipients.

Trend in Shares, by Type of R&D

Data on the split of U.S. total R&D among the three types of R&D work in previous years appear in ▦Table 4-4. Care is needed in drawing trend conclusions from these data, for reasons discussed in the notes for ▦Table 4-4.[9] Nonetheless, the table's data indicate that the shares of basic research, applied research, and development were largely the same between 2010 and 2015—and, furthermore, were also not dramatically different in the more distant past. Adjusted for inflation, U.S. overall performance of basic research is somewhat higher in 2015 ($75.9 billion) than in 2010 ($75.0 billion). More substantial increases are registered for applied research ($88.3 billion in 2015, compared to $78.3 billion in 2010) and experimental development ($285.9 billion in 2015, compared to $248.4 billion in 2010).

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[1] In this chapter, dollars adjusted for inflation (i.e., constant dollars) are based on the GDP implicit price deflator (currently in 2009 dollars) as published by the Department of Commerce, BEA (https://www.bea.gov/iTable/index_nipa.cfm). A 1953–2015 time series for this deflator appears in Appendix Table 4-1. Note that GDP deflators are calculated on an economy-wide scale and do not explicitly focus on R&D.

[2] Because of sample variability in the data for the business R&D component, the reported totals for 2009 and 2010 are not significantly different from one another at a 90% confidence level.

[3] The data for academic R&D reported in this chapter adjust the academic fiscal year basis of NSF's Higher Education Research and Development Survey data to calendar year and net out pass-throughs of research funds to remove double-counting in the national totals. Accordingly, the academic data reported in this chapter may differ from those cited in Chapter 5.

[4] Federal intramural R&D performance includes the spending for both agency laboratory R&D and for agency activities to plan and administer intramural and extramural R&D projects.

[5] NCSES maintains a current Master Government List of Federally Funded R&D Centers. For information on the current FFRDC count, along with its history, see https://www.nsf.gov/statistics/ffrdclist/. The R&D expenditure data cited here are for all the FFRDCs as an aggregate. For data on individual FFRDCs, see NCSES's annual FFRDC Research and Development Surveys at https://www.nsf.gov/statistics/srvyffrdc/.

[6] This figure does not include federal government investments in R&D infrastructure and equipment, which support the maintenance and operation of unique research facilities and the conduct of research activities that would be too costly or risky for a single company or academic institution to undertake.

[7] R&D funding by business in this section refers to nonfederal funding for domestic business R&D plus business funding for FFRDCs and U.S. academic and nonprofit R&D performers.

[8] The Organisation for Economic Co-Operation and Development notes that in measuring R&D, one source of error is the difficulty of locating the dividing line between experimental development and the further downstream activities needed to realize an innovation (OECD 2015:51–52). Most definitions of R&D set the cutoff at the point when a particular product or process reaches "market readiness." At this point, the defining characteristics of the product or process are substantially set—at least for manufactured goods, if not also for services—and further work is primarily aimed at developing markets, engaging in preproduction planning, and streamlining the production or control system.

[9] The arithmetic is straightforward to calculate type-of-R&D shares for past years, based on the data in Appendix Table 4-2 through Appendix Table 4-5. Nonetheless, care must be taken in describing the trends for these shares over time. Although NCSES's sectoral surveys of R&D expenditures have consistently used the OECD Frascati Manual's type-of-R&D definitions, the survey instruments have occasionally been revised to improve the reliability of the responses received, most notably in the academic, business, and FFRDC R&D expenditure surveys. Accordingly, some differences observed in the shares directly

calculated from the appendix table time series data more nearly reflect the effects of these improvements in the type-of-R&D survey questions than changes in the type-of-R&D shares among R&D performers.

Cross-National Comparisons of R&D Performance

Data on R&D expenditures and intensity by country and region provide a broad picture of the global distribution of R&D capabilities and activities and changes under way. Data provided periodically by the Organisation for Economic Co-operation and Development (OECD) (covering its 35 member countries and 7 selected nonmembers) and by the United Nations Educational, Scientific, and Cultural Organization (UNESCO) Institute for Statistics (covering more than 100 other countries) are useful for this comparative task (OECD 2017; UNESCO 2017).

Cross-national comparisons of R&D expenditures and funding necessarily involve currency conversions. The analysis in this section follows the international convention of converting all foreign currencies into U.S. dollars via purchasing power parity (PPP) exchange rates. (For a discussion of this methodology, see sidebar Comparing International R&D Expenditures.)

SIDEBAR

Comparing International R&D Expenditures

Comparisons of international R&D statistics are hampered by the lack of R&D-specific exchange rates. Two approaches are commonly used: (1) express national R&D expenditures as a percentage of gross domestic product (GDP) or (2) convert all expenditures to a single currency. The first method is straightforward but permits only gross comparisons of R&D intensity. The second method permits absolute level-of-effort comparisons and finer-grain analyses but entails selecting an appropriate method of currency conversion. The choice is between market exchange rates (MERs) and purchasing power parities (PPPs), both of which are available for many countries over an extended period.

MERs represent the relative value of currencies for cross-border trade of goods and services but may not accurately reflect the cost of nontraded goods and services. They are also subject to currency speculation, political events, wars or boycotts, and official currency intervention. PPPs were developed to overcome these shortcomings (Ward 1985). They take into account the cost differences of buying a similar market basket of goods and services covering tradables and nontradables. The PPP basket is assumed to be representative of total GDP across countries. PPPs are the preferred international standard for calculating cross-country R&D comparisons and are used in all official R&D tabulations of the Organisation for Economic Co-Operation and Development (OECD).*

Because MERs tend to understate the domestic purchasing power of developing countries' currencies, PPPs can produce substantially larger R&D estimates than MERs for these countries. For example, China's R&D expenditures in 2013 (as reported to the OECD) were $334 billion in PPP terms but only $191 billion using MERs. However, PPPs for large developing countries such as China and India are often rough approximations and have shortcomings. For example, structural differences and income disparities between developing and developed countries may result in PPPs based on markedly different sets of goods and services. In addition, the resulting PPPs may have very different relationships to the cost of R&D in different countries.

R&D performance in developing countries often is concentrated geographically in the most advanced cities and regions in terms of infrastructure and level of educated workforce. The costs of goods and services in these areas can be substantially greater than for the country as a whole.

* Some unresolved questions remain about the use of GDP PPPs for deflating R&D expenditures. In analyzing the manufacturing R&D inputs and outputs of six industrialized OECD countries, Dougherty et al. (2007:312) concluded that "the use of an R&D PPP will yield comparative costs and R&D intensities that vary substantially from the current practice of using GDP PPPs, likely increasing the real R&D performance of the comparison countries relative to the United States." The issue, and what if anything to do about it, remains unresolved.

Country and Regional Patterns in Total National R&D

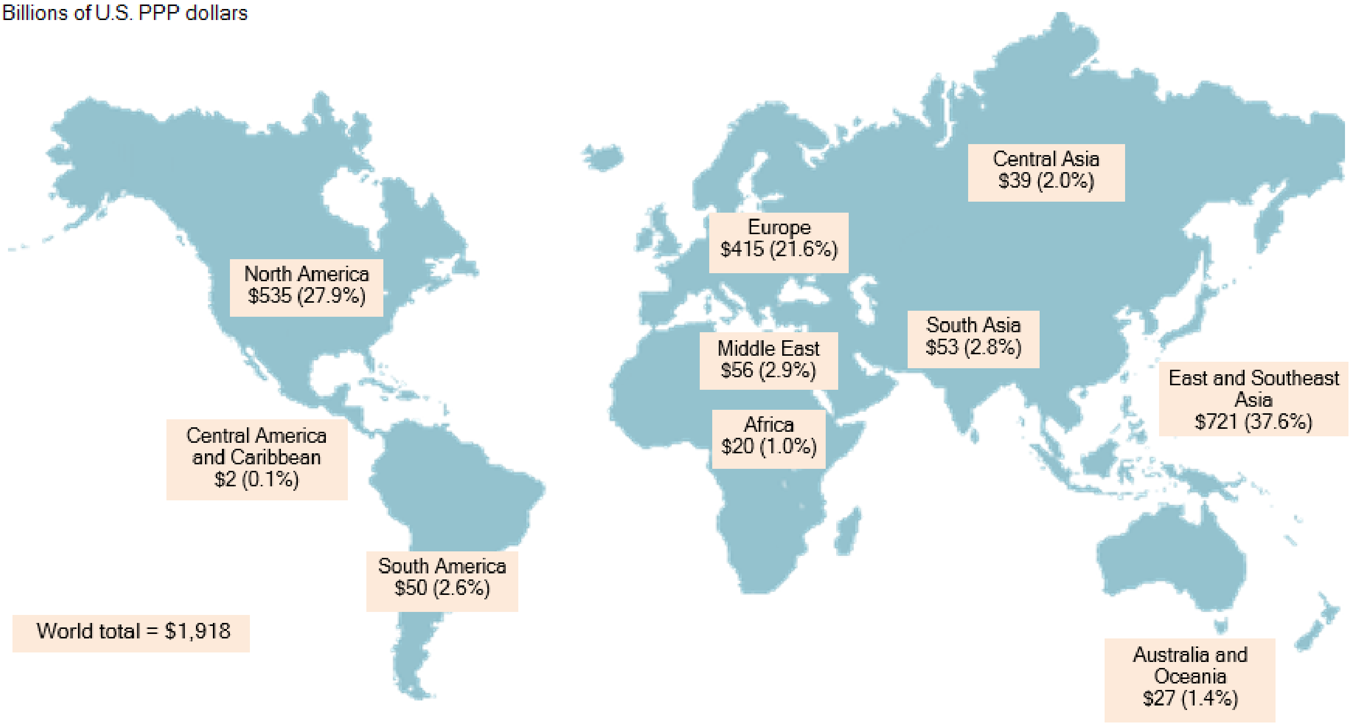
The global total of R&D expenditures continues to rise at a substantial pace. NCSES's latest estimate puts the worldwide total at $1.918 trillion (current PPP dollars) in 2015 (Figure 4-5).[1] The corresponding estimate for 5 years earlier in 2010 was $1.415 trillion. In 2000, it was $722 billion. By these figures, the annual increase in total global R&D averaged 6.3% over the 2010–15 period and 7.0% over 2000–10. (As a point of comparison, U.S. GDP totaled $18.121 trillion in 2015.)

Global R&D performance continues to remain concentrated in three geographic regions: North America, Europe, and the regions of East/Southeast and South Asia (Figure 4-5). North America (United States, Canada, Mexico) accounted for 28%

($535 billion) of worldwide R&D performance in 2015; Europe, including the European Union (EU) (see this chapter's Glossary for a list of the 28 EU member countries), accounted for 22% ($415 billion); the combination of the regions of East/Southeast and South Asia (including China, Japan, South Korea, India, and Taiwan) accounted for 40% ($773.5 billion). The remaining 10% of global R&D comes (in order) from the regions of the Middle East, South America, Central Asia, Australia and Oceania, Africa, and Central America and the Caribbean.

FIGURE 4-5

Global R&D expenditures, by region: 2015



PPP = purchasing power parity.

Note(s)

Foreign currencies are converted to dollars through PPPs. Some country data are estimated. Countries are grouped according to the regions described by *The World Factbook*, https://www.cia.gov/library/publications/resources/the-world-factbook/index.html.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics estimates, October 2017. Based on data from the Organisation for Economic Co-operation and Development, *Main Science and Technology Indicators* (2017/1), and the United Nations Educational, Scientific and Cultural Organization Institute for Statistics Data Centre, data.uis.unesco.org, accessed 13 October 2017.

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The geographic concentration of R&D is more sharply apparent when the profiles of specific countries or economies are considered (▦ Table 4-5). The United States remains the largest R&D performer ($497 billion in 2015), accounting for 26% of the global total. China was the second largest performer ($409 billion) in 2015, accounting for about 21% of the global total. Japan is third at 9% ($170 billion); Germany is fourth at 6% ($115 billion). South Korea ($74 billion), France ($61 billion), India ($50 billion), and the United Kingdom ($46 billion) make up a third tier of performers—each accounting for 2%–4% of the global R&D total. Brazil, Russia, Taiwan, and Italy make up a fourth tier, with annual R&D expenditures ranging from $30 billion to $38 billion, each accounting for 2% of the global total. Canada, Australia, and Spain are a next rung down, with annual R&D expenditures in the $20 billion–$27 billion range and each being about 1% of the global total. The United States and China together accounted for about 47% of the global R&D total in 2015, the top 8 countries accounted for 74%, and all 15 of the countries mentioned accounted for 85% of the global total.

TABLE 4-5

International comparisons of gross domestic expenditures on R&D and R&D share of gross domestic product, by region, country, or economy: 2015 or most recent year

(PPP millions of dollars and GERD-to-GDP ratio)

Region, country, or economy	GERD (PPP $millions)	GERD/GDP (%)
North America		
United States (2015)[a]	496,585.0	2.74
Canada (2015)	27,071.1	1.71
Mexico (2015)	11,563.4	0.53
Central America and Caribbean		
Cuba (2013)	1,113.5	0.47
Ecuador (2014)	805.5	0.44
South America		
Brazil (2014)	38,447.9	1.17
Argentina (2015)	5,577.1	0.63
Colombia (2015)	1,612.8	0.24
Chile (2015)	1,603.7	0.38
Europe		
Germany (2015)	114,778.1	2.93
France (2015)	60,818.7	2.22
United Kingdom (2015)	46,259.8	1.70
Italy (2015)	30,102.1	1.33
Spain (2015)	19,734.5	1.22
Switzerland (2015)	17,688.3	3.42
Netherlands (2015)	16,909.7	1.99
Sweden (2015)	15,371.7	3.28
Austria (2015)	13,321.2	3.12
Belgium (2015)	12,624.6	2.46
Poland (2015)	10,239.8	1.00

Region, country, or economy	GERD (PPP $millions)	GERD/GDP (%)
Denmark (2015)	8,236.2	2.96
Czech Republic (2015)	6,927.4	1.95
Finland (2015)	6,712.4	2.90
Norway (2015)	6,218.4	1.93
Portugal (2015)	3,921.5	1.28
Hungary (2015)	3,584.8	1.38
Ireland (2014)	3,638.7	1.54
Greece (2015)	2,765.9	0.97
Romania (2015)	2,136.6	0.49
Ukraine (2015)	2,100.9	0.62
Slovak Republic (2015)	1,911.6	1.18
Slovenia (2015)	1,458.9	2.21
Bulgaria (2015)	1,253.0	0.96
Lithuania (2015)	871.4	1.04
Belarus (2015)	870.2	0.52
Serbia (2015)	866.5	0.87
Croatia (2015)	808.1	0.85
Luxembourg (2015)	761.0	1.28
Estonia (2015)	569.3	1.50
Middle East		
Turkey (2015)	16,604.5	0.88
Israel (2015)	13,023.6	4.25
Saudi Arabia (2013)	12,513.3	0.82
United Arab Emirates (2015)	5,546.4	0.87
Iran (2012)	4,172.3	0.33
Africa		
Egypt (2015)	7,217.9	0.72

Region, country, or economy	GERD (PPP $millions)	GERD/GDP (%)
South Africa (2013)	4,975.0	0.73
Morocco (2010)	1,483.6	0.73
Nigeria (2007)	1,374.8	0.22
Tunisia (2015)	815.2	0.63
Kenya (2010)	788.2	0.79
Ethiopia (2013)	785.9	0.60
Tanzania (2013)	623.8	0.53
Central Asia		
Russian Federation (2015)	38,135.5	1.10
Khazakhstan (2015)	744.8	0.17
South Asia		
India (2015)	50,269.4	0.63
Pakistan (2015)	2,325.1	0.25
East and Southeast Asia		
China (2015)	408,829.0	2.07
Japan (2015)	170,003.0	3.29
South Korea (2015)	74,051.5	4.23
Taiwan (2015)	33,564.1	3.05
Singapore (2014)	10,102.5	2.18
Malaysia (2015)	10,637.6	1.30
Thailand (2015)	6,947.5	0.63
Indonesia (2013)	2,130.3	0.08
Viet Nam (2013)	1,777.4	0.37
Philippines (2013)	886.5	0.14
Australia and Oceania		
Australia (2013)	23,133.6	2.11
New Zealand (2015)	2,227.9	1.28

Region, country, or economy	GERD (PPP $millions)	GERD/GDP (%)
Selected country groups		
European Union (2015)	386,466.8	1.96
OECD (2015)	1,247,981.0	2.38
G-20 countries (2015)	1,766,356.4	1.92

G20 = Group of Twenty; GDP = gross domestic product; GERD = gross domestic expenditures on R&D; OECD = Organisation for Economic Co-operation and Development; PPP = purchasing power parity.

[a] Data for the United States in this table may differ slightly from those cited earlier in the chapter. Data here reflect international standards for calculating GERD, which vary slightly from the National Science Foundation's methodology for tallying U.S. total R&D.

Note(s)

Year of data is listed in parentheses. Foreign currencies are converted to dollars through PPPs. Countries in this table have an annual GERD of $500 million or more. Countries are grouped according to the regions described by *The World Factbook*, https://www.cia.gov/library/publications/resources/the-world-factbook/index.html. Data for Israel are civilian R&D only. See sources below for GERD statistics on additional countries.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Patterns of R&D Resources (annual series); OECD, *Main Science and Technology Indicators* (2017/1); United Nations Educational, Scientific and Cultural Organization Institute for Statistics Data Centre, http://data.uis.unesco.org/, accessed 13 October 2017.

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The R&D total for the EU as a whole in 2015 was $386 billion—now noticeably behind China's $409 billion for the year. Among the EU countries, Germany, with $115 billion in 2015, is by far the largest R&D performer. France ($61 billion), the United Kingdom ($46 billion), and Italy ($30 billion) are next in order.

The generally vigorous pace at which total global R&D has increased, more than two and a half times over the 2000–15 period and continuing to grow, remains among the most prominent developments—a continued reflection of the escalating knowledge intensiveness of the economic competition among the world's nations (see Chapter 6 for a further discussion). Another major trend is the sustained, large increases in the levels of R&D performance in the regions of East/Southeast and South Asia compared with the other major R&D performing areas. R&D performed in the North American region accounted for 40% of the global total in 2000 but declined to 31% in 2010 and further down to 28% in 2015. Europe accounted for 27% in 2000, 23% in 2010, and then down to 22% in 2015. The regions of East/Southeast and South Asia comprised 25% of the global total in 2000 but rose to 35% in 2010 and even higher to 40% in 2015. Present regional growth trends in R&D performance suggest the ascendant primacy of these areas of Asia is unlikely to end soon.

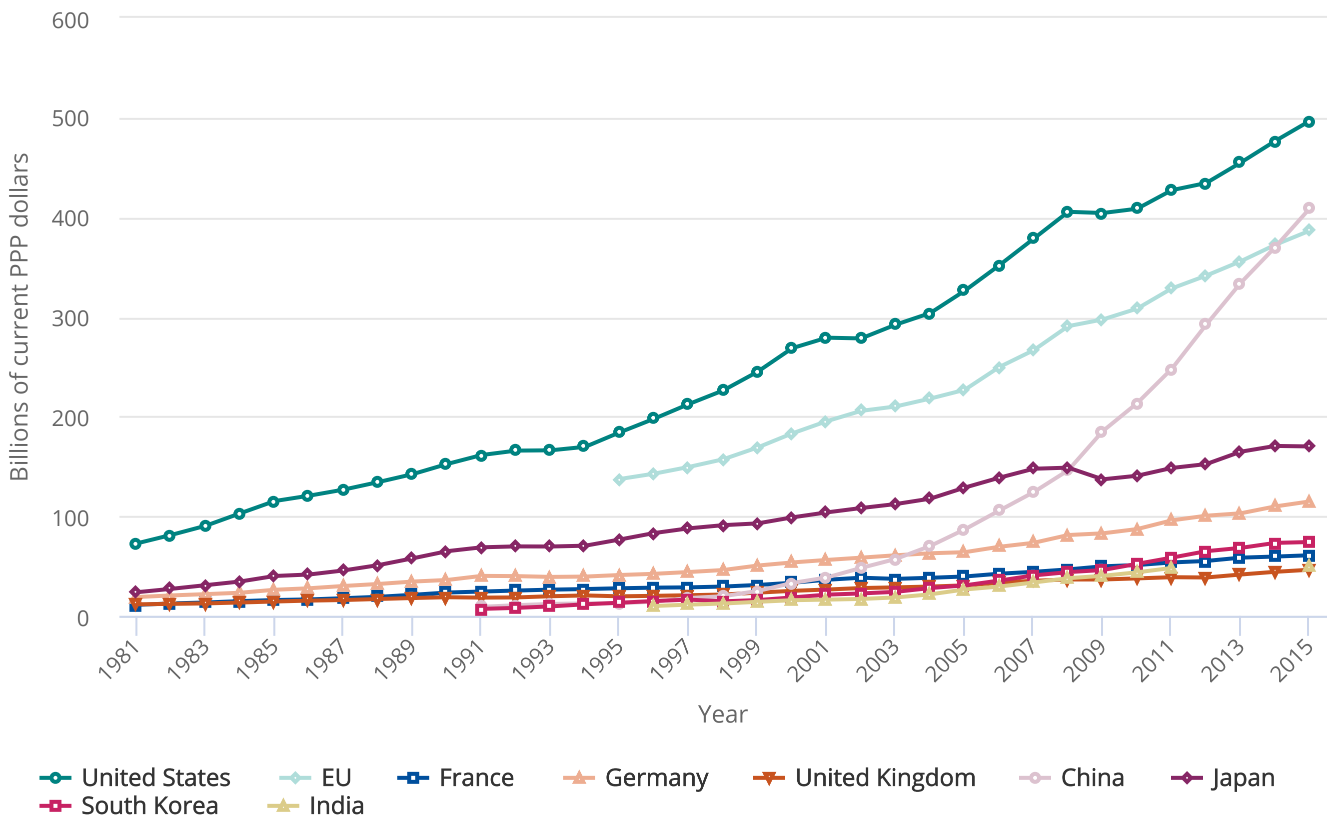
Total global R&D increased by some $1.196 trillion (current dollars) from 2000 to 2015—as noted earlier, the 2000 total was $723 billion, rising to $1.918 trillion in 2015. China alone accounted for 31% ($376 billion) of the global increase over this 15-year period. The United States accounted for 19% ($228 billion) of the global increase, and the EU accounted for 17% ($203 billion). The increases of several other major Asian R&D performers were also noticeable: Japan accounted for 6% of the increase ($71 billion), and South Korea accounted for 5% ($56 billion).

China continues to exhibit the world's most dramatic R&D growth pattern (Figure 4-6; Appendix Table 4-12). The pace of its increase in R&D performance has been exceptionally high over numerous years, averaging 20.5% annually over 2000–10 and 13.9% for 2010–15 (or 18.0% and 12.0%, respectively, when adjusted for inflation). The rate of growth in South Korea's R&D has also been quite high, averaging 10.9% annually over 2000–10 and 7.3% for 2010–15. Japan's corresponding rates of R&D growth have been slower, at 3.6% and 3.9%.

Although the United States remains well atop the list of the world's R&D-performing nations, its pace of growth in R&D performance has averaged 4.3% over 2000–10 and 4.0% for 2010–15, and its share of global R&D has declined from 37% in 2000 to 26% in 2015. Total R&D by EU nations has been growing at an annual average rate of 5.4% in 2000–10 and 4.6% in 2010–15—with Germany at 5.0% and 5.7%, France at 4.4% and 3.6%, and the United Kingdom at 4.1% and 4.2%. The EU countries accounted for 25% of total global R&D in 2000 but dropped to 20% in 2015.

FIGURE 4-6

Gross domestic expenditures on R&D, by the United States, the EU, and selected other countries: 1981–2015



EU = European Union; PPP = purchasing power parity.

Note(s)

Data are for the top eight R&D-performing countries and the EU. Data are not available for all countries for all years. Data for the United States in this figure reflect international standards for calculating gross expenditures on R&D, which vary slightly from the National Science Foundation's protocol for tallying U.S. total R&D. Data for Japan for 1996 onward may not be consistent with earlier data because of changes in methodology. Data for Germany for 1981–90 are for West Germany.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Patterns of R&D Resources (annual series); Organisation for Economic Co-operation and Development, *Main Science and Technology Indicators* (2017/1); United Nations Educational, Scientific and Cultural Organization Institute for Statistics Data Centre, data.uis.unesco.org, accessed 13 October 2017. See Appendix Table 4-12.

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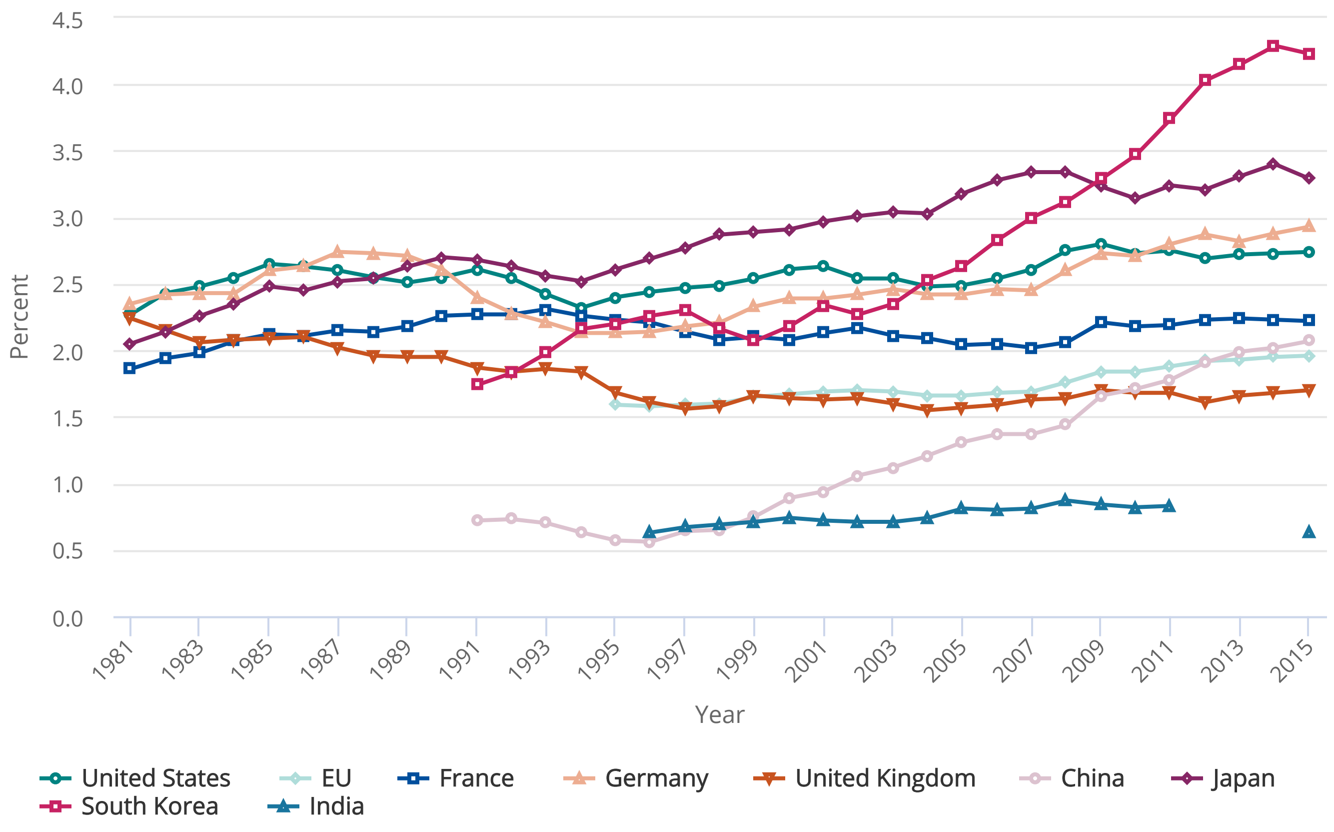
Country and Regional Patterns in National R&D Intensity

As discussed earlier in this chapter, the U.S. R&D-to-GDP ratio was 2.61% in 2000, peaked at 2.80% in 2009, dropped modestly over the next several years, but then moved upward again to 2.74% in 2015 (Figure 4-7).

At the 2015 level, the United States is 11th in R&D intensity among the economies tracked by OECD and UNESCO data. Israel and South Korea are essentially tied for the top spot, with ratios of 4.3% and 4.2%, respectively (although Israel's data exclude expenditures for defense R&D, while South Korea's data include them). Israel has long been at the top of the R&D-to-GDP ratio ranking (Table 4-5). But South Korea's upward movement has been particularly rapid since the late 1990s (Figure 4-7); furthermore, South Korea is one of the world's largest R&D performers, with annual R&D expenditures many times that of Israel. Switzerland is third, at 3.4%. Japan is fourth, at 3.3%. Several smaller countries or economies with comparatively high R&D-to-GDP ratios are Sweden (3.3%), Austria (3.1%), Taiwan (3.1%), Denmark (3.0%), Germany (2.9%), and Finland (also 2.9%). The other top 8 R&D performers include France at 2.2%, China at 2.1%, the United Kingdom at 1.7%, and India at 0.6%.

FIGURE 4-7

Gross domestic expenditures on R&D as a share of gross domestic product, by the United States, the EU, and selected other countries: 1981–2015



EU = European Union.

Note(s)

Data are for the top eight R&D-performing countries and the EU. Data are not available for all countries for all years. Data for the United States in this figure reflect international standards for calculating gross expenditures on R&D, which vary slightly from the National Science Foundation's protocol for tallying U.S. total R&D. Data for Japan for 1996 onward may not be consistent with earlier data because of changes in methodology. Data for Germany for 1981–90 are for West Germany.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Patterns of R&D Resources (annual series); Organisation for Economic Co-operation and Development, *Main Science and Technology Indicators* (2017/1); United Nations Educational, Scientific and Cultural Organization Institute for Statistics Data Centre, data.uis.unesco.org, accessed 13 October 2017. See Appendix Table 4-12.

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The U.S. rank in this indicator has been slowly falling in recent years as other countries have expanded the range and scope of their R&D activities: 11th in 2013 (as reported in *Science and Engineering Indicators 2016*), 10th in 2011 (as reported in *Science and Engineering Indicators 2014*), and 8th in 2009 (as reported in *Science and Engineering Indicators 2012*). The U.S. ranking has fallen despite the generally high U.S. R&D intensity levels (relative to historic levels) over these recent years.

The ratio has been rising gradually for the EU as a whole over the 2000–15 period, from about 1.7% in 2000 to nearly 2.0% in 2015 (📊Figure 4-7). For the largest R&D performers among the EU countries, the ratios for Germany, France, and the United Kingdom have gradually risen over 2000–15.

Among the large Asian R&D performers, Japan's R&D-to-GDP ratio has moved mainly upward in recent years, from 2.9% in 2000 to 3.3% in 2015. The high risers—across all the 8 countries considered here—have been China and South Korea. China's ratio doubled over the period, from just over 0.9% in 2000 to about 2.1% in 2015, suggesting that ample room remains for future increases (Appendix Table 4-12). South Korea's ratio increased from 2.2% in 2000 to 4.2% in 2015.

Comparisons of the Composition of Country R&D Performance

The business sector is the predominant R&D performer for nearly all the current top R&D-performing nations (▦Table 4-6). For the United States, the business sector accounted for 72% of gross expenditures on R&D in 2015. The shares were even higher in the leading Asian R&D performers: China, where the business sector accounted for 77% of the country's total R&D in 2015; Japan, where it accounted for 79%; and South Korea, where it accounted for 78%. The levels in Germany (69%), France (65%), and the United Kingdom (66%) were somewhat lower. The apparent exception is India, where the country's business sector accounted for a much smaller share of the national R&D total—44% in 2015.

TABLE 4-6

Gross expenditures on R&D for selected countries, by performing sector and source of funds: 2015 or most recent year

(PPP billions of dollars and percent share)

Country	GERD (PPP $billions)	R&D performance: Share of total (%)				R&D source of funds: Share of total (%)			
		Business	Government	Higher education	Private nonprofit	Business	Government	Other domestic	From abroad
United States (2015)[a]	496.6	71.7	11.3	13.0	4.0	62.4	25.5	7.1	5.0
China (2015)	408.8	76.8	16.2	7.0	na	74.7	21.3	NA	0.7
Japan (2015)	170.0	78.5	7.9	12.3	1.3	78.0	15.4	6.1	0.5
Germany (2015)	114.8	68.7	14.1	17.3	**	65.6	27.9	0.4	6.2
South Korea (2015)	74.1	77.5	11.7	9.1	1.6	74.5	23.7	1.0	0.8
France (2015)	60.8	65.1	13.1	20.3	1.6	55.7	34.6	2.0	7.8
India (2015)	50.3	43.6	52.5	3.9	na	NA	NA	NA	NA
United Kingdom (2015)	46.3	65.7	6.8	25.6	1.9	48.4	28.0	6.0	17.6

** = included in data for other performing sectors. na = not applicable; country does not recognize the category or does not report the data item. NA = not available.

GERD = gross domestic expenditures on R&D; PPP = purchasing power parity.

[a] Data for the United States in this table reflect international standards for calculating GERD, which vary slightly from the National Science Foundation's protocol for tallying U.S. total R&D. The data for U.S. funding from abroad include funding for business R&D and academic R&D.

Note(s)

Top 8 R&D performing countries in 2015. Complete data for India are not currently available. Percentages may not add to 100 because of rounding. Year of data is listed in parentheses.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Patterns of R&D Resources (annual series); Organisation for Economic Co-operation and Development, *Main Science and Technology Indicators* (2017/1); United Nations Educational, Scientific and Cultural Organization Institute for Statistics Data Centre, data.uis.unesco.org, accessed 13 October 2017.

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R&D performed by the government accounted for about 11% of the national total in the United States in 2015. This primarily includes activities by the federal government but also includes the small amount of R&D by nonfederal government (state) performers. The share ranged from 7% to 53% across the other countries. South Korea (12%) showed a similar share as the United States. The United Kingdom (7%) and Japan (8%) were both lower. The other countries arrayed around the United States include China (16%), Germany (14%), and France (13%). The government share in India was by far the highest, at 53%.

R&D performed by the higher education sector ranged from 4% to 26% of total national R&D across these countries. This sector's performance share for the United States was about 13% in 2015. China was at 7% that year; similarly, South Korea (9%) was also below the U.S level. Japan (12%) and Germany (17%) were near the U.S. level. France (20%) and the United Kingdom (26%) were both noticeably higher. India had by far the lowest level, at 4%.

Business sectors were the predominant source of R&D funding (▦ Table 4-6). (Although comparable data on R&D funding sources are not available for India.) For the United States, the business sector (domestic) accounted for about 62% of all U.S. R&D in 2015. China, Japan, and South Korea had substantially higher percentages, at 75%, 78%, and 75%, respectively. Germany's share was higher than that of the United States, at 66%; the United Kingdom's was lower, at 48%.

Government was the second major source of R&D funding for these countries. For the United States, government (federal and nonfederal) accounted for 26% of the nation's R&D in 2015. Germany's (28%) and the United Kingdom's (28%) shares were somewhat higher than that of the United States. South Korea's was just under, at 24%, and China's was further below, at 21%. France's was considerably higher, at 35%.

Funding from abroad refers to funding from businesses, universities, governments, nonprofits, and other organizations located outside of the country. Among the top R&D-performing countries, the United Kingdom is the most notable in this category, with 18% of R&D funding coming from abroad in 2015. France is also comparatively high, at nearly 8%. Germany was at 6%, and the United States was around 5%. The rest are much lower. (For the United States, the funding from abroad reflects foreign funding for domestic R&D performance mainly by the business and higher education sectors.)

Another dimension for comparing the top R&D-performing countries is the levels and shares of overall national annual R&D performance devoted to basic research, applied research, and experimental development. (Type-of-R&D data are not available for some countries, including Germany, in ▦ Table 4-7.)

The portion of annual R&D that countries allocate to basic research ranges between 5% and 24% (▦ Table 4-7). For the United States, this share is on the high side of the range: 17% of its overall R&D in 2015, which amounted to $83.9 billion of basic research performance that year. France often has a higher share; in 2015, it was 24%, but this amounted to $14.8 billion of basic research performance, which was well below the U.S. level. Among the top R&D-performing countries, China's basic research share is the lowest, at slightly more than 5% in 2015; however, this still amounted to about $21 billion of basic research performance that year.

TABLE 4-7

Gross expenditures on R&D for selected countries, by type of work: 2015 or most recent year

(PPP billions of dollars and percent share)

Country	GERD (PPP $billions)	Basic	Applied	Experimental development	Other nec
PPP $billions					
United States (2015)a	496.6	83.9	97.3	315.3	0.0
China (2015)	408.8	20.8	44.2	344.2	0.0
Japan (2015)	170.0	20.2	33.8	108.3	7.7
Germany (2015)	114.8	NA	NA	NA	NA
South Korea (2015)	74.1	12.7	15.4	45.9	0.0
France (2015)	60.8	14.8	22.9	21.1	2.0
India (2015)	50.3	8.0	11.2	11.8	19.3
United Kingdom (2015)	46.3	7.8	20.0	18.4	0.0
Share of total (%)					
United States (2015)[a]		16.9	19.6	63.5	0.0
China (2015)		5.1	10.8	84.2	0.0
Japan (2015)		11.9	19.9	63.7	4.5
Germany (2015)		NA	NA	NA	NA
South Korea (2015)		17.2	20.8	61.9	0.0
France (2014)		24.4	37.6	34.7	3.3
India (2009)		16.0	22.3	23.5	38.3
United Kingdom (2014)		16.9	43.3	39.8	0.0

NA = not available.

GERD = gross domestic expenditures on R&D; nec = not elsewhere classified; PPP = purchasing power parity.

[a] Data for the United States in this table reflect international standards for calculating GERD, which vary slightly from the National Science Foundation's protocol for tallying U.S. total R&D.

Note(s)

Top 8 R&D performing countries in 2015. Year of data is listed in parentheses. Detail may not add to total because of rounding. Expenditure levels by type of R&D in top panel are based on type of R&D shares in bottom panel. In some cases, the data for type of R&D shares are not as recent as total R&D performance. Complete data are not presently available for Germany.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Patterns of R&D Resources (annual series); Organisation for Economic Co-operation and Development, *Main Science and Technology Indicators* (2017/1); United Nations Educational, Scientific and Cultural Organization Institute for Statistics Data Centre, data.uis.unesco.org/, accessed 13 October 2017.

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The shares for applied research for these countries range from 11% (China) to 43% (United Kingdom), with the U.S. share nearly in the middle, at 20%. Nonetheless, in terms of overall volume, the United States dominates this category, with $97.3 billion of applied research spending in 2015. The overall volume of spending by the second and third ranked countries in this category are comparatively far behind: China, at $44.2 billion, and Japan, at $33.8 billion.

With regard to experimental development, China exhibits the highest share by far—84% of its R&D total in 2015, which was $344.2 billion of spending in this category that year. For the United States, the development share that year was 64%, totaling $315.3 billion of spending in this category. Japan and South Korea also exhibit comparatively high shares for development, respectively, 64% and 62% in 2015; however, the dollar amounts of those countries' performances were well below the levels for China and the United States.

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[1] The figures cited for total global R&D in 2000, 2010, and 2015 are NCSES estimates. R&D expenditures for all countries are denominated in U.S. dollars, based on PPPs. These estimates are based on data from the OECD's (2017) *Main Science and Technology Indicators* (Volume 2017/1) and from R&D statistics for additional countries assembled by UNESCO's Institute for Statistics (as of mid-October 2017). Presently, no database on R&D spending is comprehensive and consistent for all nations performing R&D. The OECD and UNESCO databases together provide R&D performance statistics for 158 countries, although the data are not current or complete for all. NCSES's estimate of total global R&D reflects 106 countries, with reported annual R&D expenditures of $50 million or more, which accounts for most of current global R&D.

U.S. Business R&D

Businesses have been the predominant performers of U.S. R&D dating back to the 1950s. In 2008, the business sector accounted for $290.7 billion (71.4%) of the $407.0 billion of U.S. total R&D (Table 4-8). In 2015, the business share was $355.84 billion (71.8%) of the $495.5 billion U.S. total. Year-to-year increases and declines in the level of business R&D performance greatly influence the U.S. R&D total. Indeed, the slowed growth and declines of U.S. R&D in the 2009–11 period owe much to the slowed growth and declines of the level of domestic business R&D in these years (Figure 4-2). (All amounts and calculations are in current dollars, unless otherwise noted.)

The business sectors of the U.S. economy are diverse, with wide differences in the goods and services provided across industries and in the various production inputs required, including roles for R&D. Historically, companies in manufacturing industries have accounted for two-thirds or more of U.S. business R&D, with the balance accounted for by companies in nonmanufacturing industries. As it turns out, however, the peaks in current U.S. business R&D stem from a relative handful of industries, classified in both the manufacturing and nonmanufacturing sectors.

TABLE 4-8

Funds spent for business R&D performed in the United States: 2008–15

(Millions of current dollars and percent share)

Sector	2008	2009	2010	2011	2012	2013	2014	2015
Current $millions								
U.S. total R&D	404,773	402,931	406,580	426,160	433,619	453,964	475,426	495,144
All business R&D[a]	290,680	282,393	278,977	294,093	302,250	322,528	340,728	355,821
Paid for by the company	232,505	224,920	221,706	238,768	247,280	264,913	282,570	296,677
From company-owned, U.S.-located units	225,848	221,104	218,187	235,426	242,674	259,908	277,272	289,892
From foreign subsidiaries	6,657	3,816	3,519	3,342	4,606	5,005	5,298	6,785
Paid for by others	58,176	57,473	57,271	55,324	54,970	57,615	58,158	59,144
Federal	36,360	39,573	34,199	31,309	30,621	29,362	26,554	26,990
Domestic companies	12,181	9,567	11,013	11,124	11,624	13,450	13,227	14,595
Foreign companies	8,876	7,648	11,015	12,007	12,093	13,791	17,246	16,317
Foreign parent[b]	NA	NA	7,102	7,438	8,486	10,445	13,407	12,579
Unaffiliated companies	NA	NA	3,913	4,569	3,607	3,346	3,839	3,738
All other organizations[c]	759	685	1,044	884	632	1,013	1,131	1,242
Source of funds as a percentage of all business R&D								
All business R&D[a]	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Paid for by the company	80.0	79.6	79.5	81.2	81.8	82.1	82.9	83.4
From company-owned, U.S.-located units	77.7	78.3	78.2	80.1	80.3	80.6	81.4	81.5
From foreign subsidiaries	2.3	1.4	1.3	1.1	1.5	1.6	1.6	1.9
Paid for by others	20.0	20.4	20.5	18.8	18.2	17.9	17.1	16.6
Federal	12.5	14.0	12.3	10.6	10.1	9.1	7.8	7.6
Domestic companies	4.2	3.4	3.9	3.8	3.8	4.2	3.9	4.1
Foreign companies	3.1	2.7	3.9	4.1	4.0	4.3	5.1	4.6
Foreign parent[b]	NA	NA	2.5	2.5	2.8	3.2	3.9	3.5
Unaffiliated companies	NA	NA	1.4	1.6	1.2	1.0	1.1	1.1

Sector	2008	2009	2010	2011	2012	2013	2014	2015
All other organizations[c]	0.3	0.2	0.4	0.3	0.2	0.3	0.3	0.3

NA = not available.

[a] Includes companies located in the United States that performed or funded R&D. Data in this table represent an aggregate of all industries in the North American Industry Classification System codes 21–33 and 42–81.

[b] Includes foreign parent companies of U.S. subsidiaries.

[c] Includes U.S. state government agencies and laboratories, foreign agencies and laboratories, and all other organizations located inside and outside the United States.

Note(s)

Detail may not add to total because of rounding. Industry classification was based on the dominant business code for domestic R&D performance, where available. For companies that did not report business codes, the classification used for sampling was assigned. This table excludes data for federally funded R&D centers.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Business R&D and Innovation Survey (annual series).

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Key Characteristics of Domestic Business R&D Performance

NCSES's annual Business R&D and Innovation Survey (BRDIS) provides data on all for-profit, nonfarm companies that are publicly or privately held and have five or more employees in the United States.[1] U.S. business R&D is the R&D performed by companies in the domestic United States, including that paid for by the company itself (from company-owned, U.S.-located units or from company subsidiaries located overseas) and that paid for by others (such as other companies, domestic or foreign, including foreign parents of U.S. subsidiaries; the federal government; nonfederal government, domestic or foreign; and nonprofit or other organizations, domestic or foreign).

Presently, most domestic R&D performance occurs in five business sectors: chemicals manufacturing (North American Industry Classification System [NAICS] 325, which includes the pharmaceuticals industry); computer and electronic products manufacturing (NAICS 334); transportation equipment manufacturing (NAICS 336, which includes the automobiles and aerospace industries); information (NAICS 51, which includes the software publishing industry); and professional, scientific, and technical (PST) services (NAICS 54, which includes the computer systems design and scientific R&D services industries) (▦ Table 4-9).[2] Although a sector's R&D performance total is influenced by both its overall economic size and the intensity of its R&D need (usually measured as dollars of R&D performance divided by total product sales), these are all sectors and industries with R&D intensities higher than others in the national economy (▦ Table 4-10).

TABLE 4-9

Funds spent for business R&D performed in the United States, by source of funds and selected industry: 2015

(Millions of dollars and percent share)

Industry and NAICS code	All R&D		Paid for by the company		Paid for by others									
					Total		Federal		Companies				All other organizations[b]	
									Domestic		Foreign[a]			
	$millions													
All industries, 21–33, 42–81[c]	355,821		296,677		59,144		26,990		14,595	i	16,317		1,242	
Manufacturing industries, 31–33	236,132		195,792		40,340		21,552	i	5,008		12,907		873	
Chemicals, 325	68,196		58,769		9,427		410		1,546		7,413		58	
Pharmaceuticals and medicines, 3254	58,675		50,242		8,432		138		1,465		6,772		57	
Other 325	9,521		8,527		995		272		81		641		1	
Machinery, 333	13,426		12,544		881	i	222		203	i	438	i	18	i
Computer and electronic products, 334	72,110		63,765		8,345		4,213		1,474		2,459		199	
Electrical equipment, appliances, and components, 335	4,335		3,852		483	i	50	i	16	i	396	i	21	i
Transportation equipment, 336	49,274		29,224		20,050	i	16,515	i	1,304	i	1,690		541	i
Automobiles, trailers, and parts, 3361–63	19,078		16,636		2,441		200	i	547	i	1,602	i	92	i
Aerospace products and parts, 3364	27,464		11,138		16,326	i	15,064	i	738	i	76	i	448	i
Other 336	2,732		1,450		1,283	i	1,251	i	19	i	12	i	1	i
Manufacturing nec, other 31–33	28,791		27,638		1,154	i	142	i	465	i	511	i	36	i
Nonmanufacturing industries, 21–23, 42–81	119,690		100,885		18,804		5,438		9,587	i	3,411	i	368	i
Information, 51	65,513		64,578		935		51		s		s		s	
Software publishers, 5112	33,248		32,500		747		22		s		s		s	
Other 51	32,265		32,078		188		29		s		s		s	
Finance and insurance, 52	5,366		5,329		38		0		6	i	0		32	i
Professional, scientific, and technical services, 54	38,626		21,915		16,710		5,323		9,074	i	2,048	i	265	i

Industry and NAICS code	All R&D		Paid for by the company		Paid for by others									
					Total		Federal		Companies				All other organizations[b]	
									Domestic		Foreign[a]			
Computer systems design and related services, 5415	14,333		12,418		1,915	i	605	i	1112	i	127	i	71	i
Scientific R&D services, 5417	16,329		3,896		12,433		2,939		7,669	i	1,684	i	141	i
Other 54	7,964		5,601		2,362	i	1,779	i	293	i	237	i	53	i
Nonmanufacturing nec, other 21–23, 42–81	10,185		9,063		1,121		64		s		s		s	
	Percentage of sector or industry totals													
All industries, 21–33, 42–81[c]	100.0		83.4		16.6		7.6		4.1		4.6		0.3	
Manufacturing industries, 31–33	100.0		82.9		17.1		9.1		2.1		5.5		0.4	
Chemicals, 325	100.0		86.2		13.8		0.6		2.3		10.9		0.1	
Pharmaceuticals and medicines, 3254	100.0		85.6		14.4		0.2		2.5		11.5		0.1	
Other 325	100.0		89.6		10.5		2.9		0.9		6.7		0.0	
Machinery, 333	100.0		93.4		6.6		1.7		1.5		3.3		0.1	
Computer and electronic products, 334	100.0		88.4		11.6		5.8		2.0		3.4		0.3	
Electrical equipment, appliances, and components, 335	100.0		88.9		11.1		1.2		0.4		9.1		0.5	
Transportation equipment, 336	100.0		59.3		40.7		33.5		2.6		3.4		1.1	
Automobiles, trailers, and parts, 3361–63	100.0		87.2		12.8		1.0		2.9		8.4		0.5	
Aerospace products and parts, 3364	100.0		40.6		59.4		54.8		2.7		0.3		1.6	
Other 336	100.0		53.1		47.0		45.8		0.7		0.4		0.0	
Manufacturing nec, other 31–33	100.0		96.0		4.0		0.5		1.6		1.8		0.1	
Nonmanufacturing industries, 21–23, 42–81	100.0		84.3		15.7		4.5		8.0		2.8		0.3	
Information, 51	100.0		98.6		1.4		0.1		s		s		s	
Software publishers, 5112	100.0		97.8		2.2		0.1		s		s		s	
Other 51	100.0		99.4		0.6		0.1		s		s		s	
Finance and insurance, 52	100.0		99.3		0.7		0.0		s		0.0		s	

Industry and NAICS code	All R&D	Paid for by the company	Paid for by others				
			Total	Federal	Companies		All other organizations[b]
					Domestic	Foreign[a]	
Professional, scientific, and technical services, 54	100.0	56.7	43.3	13.8	23.5	5.3	0.7
Computer systems design and related services, 5415	100.0	86.6	13.4	4.2	7.8	0.9	0.5
Scientific R&D services, 5417	100.0	23.9	76.1	18.0	47.0	10.3	0.9
Other 54	100.0	70.3	29.7	22.3	3.7	3.0	0.7
Nonmanufacturing nec, other 21–23, 42–81	100.0	89.0	11.0	0.6	s	s	s

i = more than 50% of value imputed; s = suppressed for reasons of confidentiality and/or reliability.

NAICS = North American Industry Classification System; nec = not elsewhere classified.

[a] Includes unaffiliated foreign companies and foreign parent companies of U.S. subsidiaries.

[b] Includes U.S. state government agencies and laboratories, foreign agencies and laboratories, and all other organizations located inside and outside the United States.

[c] R&D performed by companies in the United States.

Note(s)

Detail may not add to total because of rounding. Industry classification was based on the dominant business code for domestic R&D performance.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Business R&D and Innovation Survey, 2015.

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TABLE 4-10

Sales and R&D intensity for companies that performed or funded R&D, by selected industry: 2015

(Millions of U.S. dollars, percent, and thousands of domestic employees)

Industry and NAICS code	Domestic net sales (US$millions)[a]	R&D intensity (%)[b]	Domestic employment (thousands)[c]	
			Total	R&D[d]
All industries, 21–33, 42–81	9,049,901	3.9	18,915	1,543
Manufacturing industries, 31–33	5,358,542	4.4	10,151	916
Chemicals, 325	1,023,512	6.7	1,373	167
Pharmaceuticals and medicines, 3254	456,424	12.9	553	120
Other 325	567,088	1.7	820	47
Machinery, 333	360,719	3.7	989	82
Computer and electronic products, 334	734,610	9.8	1,355	263
Electrical equipment, appliances, and components, 335	150,020	2.9	330	28
Transportation equipment, 336	1,187,996	4.1	1,754	185
Automobiles, trailers, and parts, 3361–63	795,662	2.4	899	101
Aerospace products and parts, 3364	324,873	8.5	671	70
Other 336	67,461	4.0	184	14
Manufacturing nec, other 31–33	1,901,685	1.5	4,350	191
Nonmanufacturing industries, 21–23, 42–81	3,691,358	3.2	8,764	627
Information, 51	1,105,520	5.9	1,972	279
Software publishers, 5112	403,153	8.2	634	145
Other 51	702,367	4.6	1,338	134
Finance and insurance, 52	709,990	0.8	1,246	32
Professional, scientific, and technical services, 54	421,966	9.2	1,592	246
Computer systems design and related services, 5415	151,626	9.5	587	92
Scientific R&D services, 5417	60,922	26.8	264	82
Other 54	209,418	3.8	741	72

Industry and NAICS code	Domestic net sales (US$millions)[a]	R&D intensity (%)[b]	Domestic employment (thousands)[c]	
			Total	R&D[d]
Nonmanufacturing nec, other 21–23, 42–81	1,453,882	0.7	3,954	70

NAICS = North American Industry Classification System; nec = not elsewhere classified.

[a] Includes domestic net sales of companies that perform or fund R&D, transfers to foreign subsidiaries, and export sales to foreign companies; excludes intracompany transfers and sales by foreign subsidiaries.

[b] R&D intensity is domestic R&D paid for by the company and others and performed by the company divided by domestic net sales.

[c] Data recorded on 12 March represent employment figures for the year.

[d] Includes researchers, R&D managers, technicians, clerical staff, and others assigned to R&D groups.

Note(s)

Detail may not add to total because of rounding. Sales, R&D intensity, and total domestic employment statistics are representative of companies located in the United States that performed or funded R&D; R&D employment statistics are representative of companies located in the United States that performed R&D. Industry classification was based on dominant business code for domestic R&D performance, where available. For companies that did not report business codes, the classification used for sampling was assigned. Excludes data for federally funded R&D centers. The Business R&D and Innovation Survey does not include companies with fewer than five employees.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Business R&D and Innovation Survey (BRDIS), 2015.

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In 2015, these five business sectors accounted for $296.7 billion (83%) of the $355.8 billion business R&D performance total that year (Table 4-9). Corresponding data for earlier years are much the same. In 2008, the five sectors accounted for $244.9 billion (84%) of the $290.6 billion business R&D performance total (Appendix Table 4-13). Computer and electronic products accounted for about 20% of the business R&D performance total in 2015. From 2014 back to 2008, its share was in the 20%–22% range. Chemicals accounted for 19% of the business R&D total in 2015—most of which arose in the pharmaceuticals and medicines industry. Chemicals' share ranged from 19% to 21% in the previous years. The information sector accounted for about 18% of the business R&D performance total in 2015—nearly two-thirds of which was in software publishing. The information sector represented only 13% of the business R&D total in 2008, but its share has been rising since then. Transportation equipment (mainly the automobiles and aerospace industries) accounted for 14% in 2015 but had a higher share, at 17%, in 2008. Finally, the PST sector represented nearly 11% of the business R&D total in 2015—somewhat more than two-fifths is from the scientific R&D services industry, but R&D is also sizable in the computer systems design and related services industry. The PST sector's share of the total was 13% in 2008 and has been gradually declining.

For U.S. business R&D as a whole, performance is funded mainly by companies' own funds: 83% in 2015—the vast majority of which came from companies' units owned and located in the United States (81%), but a small amount (nearly 2%) came from companies' foreign subsidiaries (Table 4-8). The 17% remainder came from R&D performed by the company but paid for by others. Here, the federal government is the largest of these "paid for by" sources—about 8% of the business R&D

performance total in 2015. Domestic companies other than the performer accounted for 4% of the 2015 total; foreign companies (including foreign parents) accounted for 5%. The “all other organizations” category spans a diverse group: state government agencies and laboratories, foreign agencies and laboratories, and any other domestic and foreign funding organizations. But this grouping accounts for a nearly negligible share—0.3% in 2015. Looking back to 2008, the most notable change in the relative shares compared with 2015 is the declining role of federal funding—13%–14% in 2008–09, down to 8% in 2014–15 (▦ Table 4-8).

Nonetheless, there are some noteworthy differences when more narrowly defined sectors and industries are considered, particularly for the five top R&D-performing sectors (and their main industries) previously discussed (▦ Table 4-9). R&D performance funded through a company’s own funds was highest (in 2015) in the information sector, where the share was nearly 99%. By contrast, the own-funds share was 59% in the transportation equipment sector and 57% in the PST sector. Even lower shares are found in specific industries: 24% in scientific R&D services and 41% in aerospace products and parts are own-funds.

The federal funding share is greatest in the transportation equipment sector (34%), particularly in the aerospace products and parts industry (55%). The share is also markedly higher in the PST sector (14%) than the all-industries average (8%). The next highest share is in the computer and electronic products sector, at 6%.

Funding provided by other domestic companies, for most of the sectors and industries, is at or below the 4% aggregate average. The exceptions are in PST, where such funding is 24% for the sector, and in scientific R&D services, where it is at an even higher 47%. Funding provided by foreign companies was about the 5% aggregate average for the PST sector and was somewhat below for the computer and electronic products and transportation equipment sectors. Foreign funding was well below the all-industry average in the information sector (less than 1%) and well above in the chemicals sector (11%).

Apart from direct funding for R&D in the form of contracts and grants to businesses, the U.S. government offers indirect R&D support via fiscal incentives such as tax credits. For recent statistics, see sidebar 💬 Federal Research and Experimentation Tax Credit and Appendix Table 4-14.

Finally, regarding domestic business R&D performance and company size (as measured by the number of employees), ▦ Table 4-11 provides statistics for 2008–15. In 2015, the largest companies (i.e., those with 25,000 or more domestic employees) performed 36% of U.S. business R&D. On the other side, micro companies (5–9 employees) and small companies (10–49 employees) accounted together for 5%. The other 59% was spread among the size classifications between these extremes. As is apparent from the table, the distribution of all business R&D by company size has not greatly changed since 2008.

TABLE 4-11

Funds spent for business R&D performed in the United States, by size of company: Selected years, 2008–15

(Millions of dollars and percent share)

Size of company (number of domestic employees)	Millions of dollars								Percentage of all business R&D				
	2008	2010	2012		2014		2015		2008	2010	2012	2014	2015
All business domestic R&D[a]	290,680	278,977	302,250		340,728		355,821		100.0	100.0	100.0	100.0	100.0
Micro companies[b]													
5–9	NA	3,851	2,926	i	3,295	i	2,988	i	NA	1.4	1.0	1.0	0.8
Small companies													
10–24[c]	14,280	8,722	6,915	i	7,177	i	NA		4.9	3.1	2.3	2.1	NA
25–49	9,626	8,624	7,195	i	8,428	i	NA		3.3	3.1	2.4	2.5	NA
10–19[d]	NA	NA	NA		NA		5,680	i	NA	NA	NA	NA	1.6
20–49[d]	NA	NA	NA		NA		10,249	i	NA	NA	NA	NA	2.9
Medium companies													
50–99	9,351	8,855	9,182	i	10,178	i	11,509		3.2	3.2	3.0	3.0	3.2
100–249	14,662	11,866	12,480		13,492		13,602		5.0	4.3	4.1	4.0	3.8
Large companies													
250–499	10,219	10,283	11,264		12,203		13,553		3.5	3.7	3.7	3.6	3.8
500–999	11,886	10,117	11,484		13,262		15,217		4.1	3.6	3.8	3.9	4.3
1,000–4,999	46,336	48,228	50,691		57,551		58,094		15.9	17.3	16.8	16.9	16.3
5,000–9,999	24,764	27,463	30,483		38,202		38,838		8.5	9.8	10.1	11.2	10.9
10,000–24,999	48,737	41,835	49,493		54,445		59,328		16.8	15.0	16.4	16.0	16.7
25,000 or more	100,820	99,133	110,138		122,495		126,763		34.7	35.5	36.4	36.0	35.6

i = more than 50% of value imputed; NA = not available.

[a] R&D performed by companies in the domestic United States. Includes industries in NAICS 21–33, 42–81.

[b] Business R&D and Innovation Survey does not include companies with fewer than five employees.

[c] Data for 2008 include the 5–9 employees category.

[d] Employee size categories have been revised to match international classifications starting in 2015.

Note(s)

Detail may not add to total because of rounding. This table excludes data for federally funded R&D centers.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Business R&D and Innovation Survey (BRDIS) (annual series).

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SIDEBAR

Federal Research and Experimentation Tax Credit

The United States and other Organisation for Economic Co-Operation and Development (OECD) countries offer fiscal incentives for business R&D at the national and subnational levels (OECD 2017).* For businesses, tax credits reduce the after-tax costs of R&D activities. For governments, tax credits are forgone revenue, known as tax expenditures. Such incentives are generally justified by the inability of private performers to capture the full benefits of R&D, given the intangible nature and abundant spillover effects of new knowledge and information.

The U.S. research and experimentation (R&E) tax credit was originally established by the Economic Recovery Tax Act of 1981 on a temporary basis. The credit was extended on a temporary basis 16 times through 2015. It was made permanent as part of the Protecting Americans from Tax Hikes Act of 2015 (P.L. 114-113, 18 December 2015). The R&E credit is incremental, with the credit amount calculated as an applicable credit rate times the amount of qualified research expense above a base amount; under the law, taxpayers may select one of several methods to calculate the credit.** (For further details and a discussion of data on the use of the credit, see U.S. Department of the Treasury [2016]).

Based on estimates from the Internal Revenue Service (IRS) Statistics of Income, R&E tax credit claims fell to $7.8 billion in 2009 from $8.3 billion in 2008 but rebounded in subsequent years, totaling $11.3 billion in 2013 (most recent data; Appendix Table 4-14). Likewise, the number of corporate returns claiming the credit dropped in 2009 compared with 2008 but resumed an upward trend in subsequent years. R&E credit claims relative to company-funded domestic R&D have fluctuated fairly narrowly between 3.0% and 4.4% since 2001 (3.6% in 2008, 3.5% in 2009, and increasing gradually to 4.4% in 2012 and 2013).

* For general information on US and other OECD countries tax relief for business R&D see http://www.oecd.org/sti/rd-tax-stats.htm

** See Internal Revenue Code (IRC) Section 41, as amended. See also IRS Form 6765 at https://www.irs.gov/pub/irs-pdf/i6765.pdf.

Cross-National Comparisons of Business R&D

The industries currently predominant in performing business R&D in the United States are generally also the same in the other largest R&D-performing countries. Table 4-12 provides cross-national comparisons for the United States, France, Germany, the United Kingdom, China, Japan, and South Korea (corresponding statistics for India and Russia are not presently available). These data come from the OECD's Analytical Business Enterprise R&D (ANBERD) database.[3] Note that the classification of industries in this table reflects the International Standard Industrial Classification of All Economic Activities (ISIC), Revision 4 for all countries (including the United States), which differs somewhat from NAICS, which is used to report U.S. data earlier in this section of the chapter.[4] The coverage in Table 4-12 is also truncated, in that only those industries with comparatively higher levels of annual R&D performance are included—for a more complete listing of industries, see the OECD ANBERD database (as cited in Table 4-12). (All amounts and calculations are in current purchasing power parity or PPP dollars, unless otherwise noted.)

TABLE 4-12

Business expenditures for R&D, by selected countries and top R&D-performing industries: 2014 or most recent year

(PPP millions of current dollars and percent share)

Industry	ISIC Rev.4		United States (2014)	France (2013)	Germany (2014)	United Kingdom (2014)	China (2014)	Japan (2014)	South Korea (2014)
	Section	Division							
PPP current $millions									
Total business enterprise	A–U	1–99	340,728	35,956	72,425	28,151	275,257	129,062	58,156
Manufacturing	C	10–33	232,815	18,255	62,877	10,993	242,975	111,666	51,709
Chemicals and chemical products		20	9,688	1,106	4,611	517	22,477	7,157	2,771
Pharmaceuticals, medicinal chemical, and botanical products		21	56,612	943	5,127	565	10,679	14,205	1,309
Computer, electronic, and optical products		26	73,891	4,296	9,539	1,421	42,724	27,427	30,920
Motor vehicles, trailers, and semi-trailers		29	18,404	2,233	24,992	2,848	21,537	32,485	6,855
Other transport equipment		30	28,342	3,969	2,628	2,246	11,659	852	887
Air and spacecraft and related machinery		303	26,181	3,651	2,289	2,108	NA	468	88
Total services	G–U	45–99	102,039	16,630	9,008	16,580	NA	15,956	4,803
Information and communication	J	58–63	74,792	4,256	4,103	4,145	NA	6,539	2,499
Publishing activities		58	36,140	1,094	NA	117	NA	9	1,615
Software publishing		582	36,052	1,076	NA	51	NA	NA	1,600
Computer programming, consultancy, and related activities		62	11,019	1,984	3,459	2,309	NA	2,629	227

Industry	ISIC Rev.4		United States (2014)	France (2013)	Germany (2014)	United Kingdom (2014)	China (2014)	Japan (2014)	South Korea (2014)
	Section	Division							
Professional, scientific, and technical activities	M	69–75	19,956	9,785	3,982	9,837	NA	8,152	1,228
Scientific R&D		72	12,807	4,213	2,215	7,025	NA	7,442	348
Percentage of total business enterprise									
Total business enterprise	A–U	1–99	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Manufacturing	C	10–33	68.3	50.8	86.8	39.0	88.3	86.5	88.9
Chemicals and chemical products		20	2.8	3.1	6.4	1.8	8.2	5.5	4.8
Pharmaceuticals, medicinal chemical, and botanical products		21	16.6	2.6	7.1	2.0	3.9	11.0	2.3
Computer, electronic, and optical products		26	21.7	11.9	13.2	5.0	15.5	21.3	53.2
Motor vehicles, trailers, and semi-trailers		29	5.4	6.2	34.5	10.1	7.8	25.2	11.8
Other transport equipment		30	8.3	11.0	3.6	8.0	4.2	0.7	1.5
Air and spacecraft and related machinery		303	7.7	10.2	3.2	7.5	NA	0.4	0.2
Total services	G–U	45–99	29.9	46.3	12.4	58.9	NA	12.4	8.3
Information and communication	J	58-63	22.0	11.8	5.7	14.7	NA	5.1	4.3
Publishing activities		58	10.6	3.0	NA	0.4	NA	0.0	2.8
Software publishing		582	10.6	3.0	NA	0.2	NA	NA	2.8
Computer programming, consultancy, and related activities		62	3.2	5.5	4.8	8.2	NA	2.0	0.4
Professional, scientific, and technical activities	M	69–75	5.9	27.2	5.5	34.9	NA	6.3	2.1
Scientific R&D		72	3.8	11.7	3.1	25.0	NA	5.8	0.6

NA = not available.

ISIC Rev.4 = International Standard Industrial Classification of All Economic Activities, Revision 4; PPP = purchasing power parity.

Note(s)

Detail may not add to total because of rounding. Industry classifications for all countries are based on main activity. The U.S. business R&D data are from the U.S. Business R&D and Innovation Survey 2014 (cross-walked to the ISIC Rev. 4 classifications). In general, the table includes industries with annual R&D expenditures of $10 billion or more (i.e., each country's largest R&D performers). See the Organisation for Economic Co-operation and Development's (OECD's) ANalytic Business Enterprise Research and Development (ANBERD) database for a more detailed set of industries by country (source as below).

Source(s)

OECD, ANBERD database, Statistical Analysis Database, R&D Expenditures in Industry, https://stats.oecd.org/Index.aspx?DataSetCode=ANBERD_REV4, accessed 25 January 2016.

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Based on ISIC, the manufacturing section (ISIC 10–33) accounted for about 68% of the $340.7 billion of overall business R&D performance in the United States in 2014. As apparent in Table 4-12, this stemmed in large part from the relatively high levels of R&D performed in the computer, electronic, and optical products division (ISIC 26; $73.9 billion, or 22% of all business-performed R&D in the United States in 2014); the pharmaceuticals, medicinal chemical, and botanical products division (ISIC 21; $56.6 billion, 17%); and the air and spacecraft and related machinery industry (ISIC 303; $26.2 billion, 8%). (The shares reported here are not materially different from those reported earlier in this section based on the NAICS categories.)

Outside of manufacturing, a comprehensive group encompassing all services divisions (ISIC 45–99) accounted for most of the rest of U.S. business R&D in 2014 ($102.0 billion, or 30%) (Table 4-12). The information and communication section (ISIC 58–63) itself accounted for 22%, including software publishing (ISIC 582, 11%). The PST activities section (ISIC 69–75) represented 6%, including scientific research and development (ISIC 72, 4%).

For Germany, Japan, South Korea, and China, the manufacturing sector accounts for a substantially higher share of overall business R&D—87%–89%, depending on the country (Table 4-12). With Germany, the motor vehicles, trailers, and semi-trailers division (ISIC 29) accounted for 35% of the $72.4 billion of business R&D in 2014. The next largest share was computer, electronic, and optical products (ISIC 26) at 13%. For Japan, with $129.1 billion of business R&D in 2014, the R&D emphases were 25% in motor vehicles, trailers, and semi-trailers (ISIC 29); 21% in computer, electronic, and optical products (ISIC 26); and 11% in pharmaceuticals, medicinal chemical, and botanical products (ISIC 21). For South Korea, 53% of its $58.2 billion of business R&D in 2014 was in computer, electronic, and optical products (ISIC 26); the next highest share was 12% in motor vehicles, trailers, and semi-trailers (ISIC 29). China's business R&D, $275.3 billion in 2014, although conducted mainly in manufacturing, is more diverse: 16% in computer, electronic, and optical products (ISIC 26); 8% in chemicals and chemical products (ISIC 20); and 8% in motor vehicles, trailers, and semi-trailers (ISIC 29), with the rest widely spread.

France and the United Kingdom are exceptions to the manufacturing emphasis, given the quite large shares of R&D that occur in services industries (Table 4-12). For France, 51% of its $36.0 billion of business R&D in 2013 was in manufacturing, with peaks in computer, electronic, and optical products (12%) and in air and spacecraft and related machinery (10%). But 46% of France's business R&D total came from services, with 27% in the PST activities section (ISIC 69–75) and 12% in the information and communication section (ISIC 58–63). Somewhat similarly, for the United Kingdom, with $28.2 billion of business R&D in 2014, 39% is in manufacturing, with modest emphases in motor vehicles, trailers, and semi-trailers (10%) and air and spacecraft and related machinery (8%). But 59% is in services—35% in PST activities (ISIC 69–75) and 15% in information and communication (ISIC 58–63).

R&D by Multinational Enterprises

The extent and geographic spread of R&D by multinational enterprises (MNEs) are useful markers of the increasingly global character of supply chains for production and innovation in R&D-intensive sectors. These business activities reflect a mix of international economic trends, including the increased complexity of global supply chains, the deepening arrays of scientific or technological capabilities and resources around the globe, and the need to economically and strategically strengthen internal technological capabilities (Moncada-Paternò-Castello, Vivarelli, and Voigt 2011; OECD 2008).

This section is based on MNE operations data collected in annual foreign direct investment surveys conducted by the U.S. Bureau of Economic Analysis (BEA). These data cover majority-owned affiliates (those owned more than 50% by their parent companies) of foreign MNEs located in the United States (Survey of Foreign Direct Investment in the United States) and U.S. MNEs and their majority-owned foreign affiliates (Survey of U.S. Direct Investment Abroad).[5] (All amounts and calculations are in current dollars, unless otherwise noted.)

R&D Performed in the United States by Affiliates of Foreign Multinational Enterprises

Affiliates of foreign MNEs located in the United States (hereafter, U.S. affiliates) performed $56.9 billion of R&D in the United States in 2014 (Table 4-13). This was equivalent to 17% of the $340.7 billion of business R&D performed in the United States in 2014 (comparing data in Table 4-1 and Table 4-13). Both the level of U.S. affiliate R&D and its share of the total of U.S. business R&D have generally increased since the late 1990s. In 1997, U.S. affiliate R&D was $17.2 billion, or equivalent to 11% of the U.S. business total; in 2007, it was $41.0 billion, or equivalent to 15% of the U.S. business R&D total (Appendix Table 4-2 and Appendix Table 4-15).

About more than two-thirds of U.S. affiliate R&D in 2014 was performed by firms owned by parent companies based in five countries: Switzerland (19%), Japan (14%), the United Kingdom (13%), France (12%), and Germany (12%) (Table 4-13). Although the relative rankings have shifted somewhat from year to year, these have been the predominant countries throughout the last 5 years.

TABLE 4-13

R&D performed by majority-owned affiliates of foreign companies in the United States, by selected industry of affiliate and investor country: 2014

(Millions of current U.S. dollars)

Country	All industries	Manufacturing						Nonmanufacturing		
		Total	Chemicals	Machinery	Computer and electronic products	Electrical equipment, appliances, and components	Transportation equipment	Wholesale trade	Information	Professional, scientific, and technical services
All countries	56,904	41,124	22,407	2,835	5,000	1,070	6,295	8,407	1,235	4,905
Canada	509	346	1	s	s	0	212	14	75	58
Europe	42,068	34,579	19,791	2,491	3,363	997	5,225	2,790	726	3,289
France	6,749	6,242	s	s	1,625	s	s	s	287	57
Germany	7,080	5,791	2,058	s	171	19	s	238	s	s
Netherlands	2,362	1,672	252	s	s	0	s	505	3	s
Switzerland	10,551	8,539	s	45	s	s	s	s	5	1,564
United Kingdom	7,269	6,754	5,033	76	298	s	641	118	198	179
Other	8,058	5,581	1,149	229	134	s	s	1,522	s	s
Asia and Pacific	10,539	3,636	1,391	s	515	73	852	4,963	s	s
Japan	7,865	2,920	1,297	195	440	69	574	3,550	165	1,109
Other	2,674	716	94	s	75	4	279	1,412	s	s
Other	3,788	2,563	1,224	s	s	0	6	640	s	s

s = suppressed for reasons of confidentiality and/or reliability.

Note(s)

Data are preliminary and are for majority-owned (> 50%) affiliates of foreign companies by country of ultimate beneficial owner and industry of affiliate. Includes R&D conducted by foreign affiliates, whether for themselves or others under contract; excludes R&D conducted by others for affiliates.

Source(s)

Bureau of Economic Analysis, Survey of Foreign Direct Investment in the United States (annual series), https://www.bea.gov/iTable/Index_MNC.cfm, accessed 26 April 2017.

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U.S. affiliates classified in manufacturing accounted for 72% of the U.S. affiliate R&D total in 2014 (▦ Table 4-14). This manufacturing share has generally been 70% or more since 2007 (Appendix Table 4-16). The chemicals subsector share was 39%, and the pharmaceuticals share (a component of chemicals) was 36%. Other manufacturing subsectors with appreciable shares in 2014 included transportation equipment (11%), computer and electronic products (9%), and machinery (5%) (Appendix Table 4-16). For nonmanufacturing, the most notable sectors in 2014 were wholesale trade (15%) and PST services (9%). (Affiliates are classified in the industries in which they have the most sales; many affiliates classified in wholesale trade have manufacturing operations as well.)

TABLE 4-14

R&D performed abroad by majority-owned foreign affiliates of U.S. parent companies, by selected industry of affiliate and host region, country, or economy: 2014

(Millions of current U.S. dollars)

Region, country, or economy	All industries	Manufacturing						Nonmanufacturing		
		Total	Chemicals	Machinery	Computer and electronic products	Electrical equipment, appliances, and components	Transportation equipment	Wholesale trade	Information	Professional, scientific, and technical services
All countries	52,174	32,128	8,511	2,852	8,376	527	7,723	4,976	3,952	10,338
Canada	3,418	2,046	330	42	695	65	674	206	445	641
Europe	30,774	19,822	5,509	2,000	4,305	240	5,083	3,933	1,937	4,523
Austria	314	124	18	s	9	4	5	48.0	0	142
Belgium	1,151	818	609.0	19	96	1	s	71	s	230
Denmark	483	385	s	s	108	0	0	s	s	2
Finland	389	331	4	s	s	1	0	18	*	40
France	2,395	1,899	438	224	440	19	370	192	127	169
Germany	8,344	6,926	700	656	2,016	108	2,798	556	119	649
Ireland	2,415	1,472	893	*	349	s	3	s	533	295
Italy	800	637	186	240	59	9	68	28	5	128
Luxembourg	311	s	5.0	*	*	*	0	4	9	s
Netherlands	1,226	936	404	58	83	11	s	65	54	108

Region, country, or economy	All industries	Manufacturing						Nonmanufacturing		
		Total	Chemicals	Machinery	Computer and electronic products	Electrical equipment, appliances, and components	Transportation equipment	Wholesale trade	Information	Professional, scientific, and technical services
Norway	296	112	s	1.0	47	s	0	7	s	s
Poland	241	155	32	2	s	*	55	7	2	77
Russia	195	50	6	s	5	0	0	s	s	115
Spain	406	230	129.0	4	s	6	50.0	67	s	63
Sweden	711	550	82	12.0	82	5	203	21.0	70	67
Switzerland	4,140	1,525	665	s	199	s	7.0	1,927	s	s
United Kingdom	6,306	3,193	943	230	444	34	1,227	700	530	1,589
Latin America and OWH	2,333	1,724	512	163	166	s	613	109	59	343
Argentina	133	63	39	*	1	0	s	1	s	s
Brazil	1,221	1,067	315	s	38	*	531	16	36	73
Mexico	472	332	83	s	4	s	67	s	2	s
Africa	102	28	10	s	2	0	4	s	s	s
South Africa	58	24	7	s	2	0	4.0	s	*	s
Middle East	2,906	1,182	225	s	639	s	1	s	s	s
Israel	2,695	s	s	172	639	s	1	s	s	1,341

Region, country, or economy	All industries	Manufacturing						Nonmanufacturing		
		Total	Chemicals	Machinery	Computer and electronic products	Electrical equipment, appliances, and components	Transportation equipment	Wholesale trade	Information	Professional, scientific, and technical services
Asia and Pacific	12,639	7,325	1,925	467	2,569	205	1,348	568	1,265	3,453
Australia	1,185	851	142	25	32	9	s	52	128	148
China	3,036	1,494	399	92	469	121	174	89.0	s	1,053
India	2,906	909	314	158	355	s	57	s	s	1,331
Japan	2,521	1,740	937	123	460	s	s	s	148	559
Malaysia	440	430	2	1	419	0	0	3.0	2	6
Singapore	767	550	28	s	379	s	s	119	35	58
South Korea	946	825	47	19	151	0	s	17	29	75
Taiwan	387	215	20	2	165	7	5	6	31	136

* = ≤ $500,000; s = suppressed for reasons of confidentiality and/or reliability.

OWH = other Western Hemisphere.

Note(s)

Data are for majority-owned (> 50%) affiliates of U.S. parent companies by host country and industry of affiliate. Includes R&D conducted by foreign affiliates, whether for themselves or others under contract; excludes R&D conducted by others for affiliates.

Source(s)

Bureau of Economic Analysis, Direct Investment and Multinational Enterprises (annual series), https://www.bea.gov/iTable/index_MNC.cfm, accessed 27 January 2017.

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U.S. Multinational Enterprise Parent Companies and Their Foreign Affiliates

R&D performed outside the United States by majority-owned foreign affiliates of U.S. MNEs totaled $52.2 billion in 2014 (▦ Table 4-14). The parent companies of these U.S. MNEs performed $268.8 billion of R&D in the United States (Appendix Table 4-19), which was equivalent to about 79% of the total business R&D conducted in the United States that year. In 1997, foreign affiliates' R&D performance abroad was $14.6 billion; in 2007, it was $34.4 billion (Appendix Table 4-17).

European countries hosted $30.8 billion (59%) of this foreign affiliate R&D in 2014 (▦ Table 4-14). The largest R&D expenditures by U.S.-owned affiliates in this region were in Germany ($8.3 billion, 16%) and the United Kingdom ($6.3 billion, 12%). Other notable locations included Switzerland ($4.1 billion, 8%), Ireland ($2.4 billion, 5%), France ($2.4 billion, 5%), the Netherlands ($1.2 billion, 2%), and Belgium ($1.2 billion, 2%). The European share overall was 66% in 2007 and 69% in 1997 (Appendix Table 4-17). Germany and the United Kingdom were the predominant host countries over this 15-year period, although the two countries had more evenly matched shares before 2008.

Canada hosted $3.4 billion (7%) of U.S. MNE foreign affiliate R&D in 2014, a sizable amount in comparison with most other countries. Although Canada has seen increased levels of U.S. foreign affiliates' R&D performance since 1997 (albeit with some year-over-year volatility), its share has been gradually declining since then (Appendix Table 4-17).

Countries in the Asia and Pacific regions hosted $12.6 billion (24%) of U.S. foreign affiliate R&D in 2014 (▦ Table 4-14). Majority-owned affiliates of U.S. MNEs in China ($3.0 billion, 6%), India ($2.9 billion, 6%), and Japan ($2.5 billion, 5%) had the largest R&D expenditures in this region. As in other cross-national comparative indicators for R&D, the Asia/Pacific region continues to gain an increasing share as a host for U.S. parent companies' foreign affiliate R&D. The region accounted for only 13% of the total in 1997. Whereas Japan's share has remained sizable across the 1997–2014 period, though declining somewhat since the early 2000s, the growth areas for foreign affiliate R&D have been India and China, each of which accounted for a negligible share in the late 1990s but grew to exceed that of Japan by 2014 (Appendix Table 4-17).

Latin America and other Western Hemisphere countries—mostly Brazil—accounted for $2.3 billion (4%) in R&D expenditures by U.S.-owned affiliates in 2014. U.S.-owned affiliates in the Middle East—nearly all in Israel—accounted for $2.9 billion (6%) in 2014.

With respect to economic sectors, foreign affiliate R&D of U.S. MNEs was concentrated in four industries in 2014: PST services ($10.3 billion, 20%), chemicals particularly pharmaceuticals ($8.5 billion, 16%), computer and electronic products ($8.4 billion, 16%), and transportation equipment ($7.7 billion, 15%) (▦ Table 4-14). Other notable industries include wholesale trade ($5.0 billion), information ($4.0 billion), and machinery ($2.9 billion). These industries have been similarly prominent over the last several years (Appendix Table 4-18).

As noted, Europe (as a whole) and Japan remain top R&D hosts for U.S. MNEs in major industries, reflecting both strengths of the host countries in certain technologies and the large, longstanding investments by U.S. MNEs in these locations (Appendix Table 4-17). In transportation equipment, Germany is by far the largest location of U.S.-owned affiliates' R&D—$2.8 billion of the $7.7 billion total R&D in 2014 performed by majority-owned foreign affiliates of U.S. MNEs is classified in this industry (▦ Table 4-14). Similarly, for computers and electronic products manufacturing, Germany was the leading host location, with $2.0 billion in R&D expenditures out of the $8.4 billion total R&D performed by majority-owned foreign affiliates of U.S. MNEs classified in this industry. In chemicals manufacturing, the United Kingdom, Japan, and Ireland were the top locations of U.S.-owned affiliates' R&D in 2014—each accounting for $0.9 billion, of the $8.5 billion in total U.S.-owned affiliates' R&D in this industry.

For R&D performed by U.S. MNE foreign affiliates classified in PST services, the host country roles reflect both older trends and the rise of Asia as a host of U.S.-owned R&D (▦ Table 4-14). The United Kingdom hosted the largest amount of R&D

performed in this industry in 2014 ($1.6 billion of the $10.3 billion total of U.S.-owned affiliates' R&D outside the United States). The second, third, fourth, and fifth largest were, respectively, Israel ($1.3 billion), India ($1.3 billion), China ($1.1 billion), and Germany ($0.6 billion).

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[1] The Business R&D and Innovation Survey does not collect data for companies with fewer than five employees. See sidebar 💬 Measured and Unmeasured R&D.

[2] The industry-level data presented in this section are obtained by classifying a company's total R&D into a single industry, even if R&D activities occur in multiple lines of business. For example, if a company has $100 million in R&D expenses—$80 million in pharmaceuticals and $20 million in medical devices—the total R&D expense of $100 million is assigned to the pharmaceuticals industry because it is the largest component of the company's total R&D expense (Shackelford 2012). However, most companies performed R&D in only one business activity area. In 2010, 86% of companies reported domestic R&D performed by and paid for by the company related to only one business activity. See Shackelford (2012) for an in-depth analysis of the relationship between business codes and industry codes.

[3] For a description of the OECD's ANBERD methodology and data, see https://www.oecd.org/innovation/inno/anberdanalyticalbusinessenterpriseresearchanddevelopmentdatabase.htm.

[4] ISIC Revision 4 was released by the United Nations Statistics Division in August 2008. For an overview of the classification structure, comparisons with earlier editions, and background, see https://unstats.un.org/unsd/cr/registry/regcst.asp?Cl=27.

[5] For further information on the BEA surveys, see https://www.bea.gov/international.

Recent Trends in Federal Support for U.S. R&D

One of the federal government's most significant roles in supporting the U.S. R&D system is the regular stream of funding it has provided for R&D activities conducted by both federal entities (agency intramural laboratories/facilities and FFRDCs) and external, nonfederal organizations such as businesses and academic institutions. Fifteen federal departments and a dozen other agencies engage in and/or provide funding for R&D in the United States (▦ Table 4-15). Historically, the majority of the yearly federal funding total is accounted for by the R&D activities of a relatively small group of departments and agencies: Department of Defense (DOD); Department of Health and Human Services (HHS, primarily the National Institutes of Health [NIH]); Department of Energy (DOE); National Aeronautics and Space Administration (NASA); National Science Foundation (NSF); Department of Agriculture (USDA); and Department of Commerce (DOC).

TABLE 4-15

Federal obligations for R&D and R&D plant, by agency: FYs 2007–16

(Millions of dollars)

Agency	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016[a]
All agencies	129,431.2	129,049.5	144,758.1	146,967.8	139,661.5	140,629.1	127,291.1	132,496.3	131,398.2	142,555.0
Department of Defense	72,290.5	71,996.6	75,973.7	73,623.9	75,327.6	73,973.6	63,654.7	65,128.6	61,683.0	69,076.4
Department of Health and Human Services	29,556.1	29,700.7	35,735.9	37,616.9	30,928.0	31,335.8	29,512.8	30,799.1	30,425.5	32,047.4
Department of Energy	8,629.8	8,990.3	11,562.2	11,644.9	10,680.4	10,635.2	10,397.1	11,296.3	12,343.0	13,303.7
National Aeronautics and Space Administration	6,205.8	5,847.1	5,957.6	8,691.3	8,429.0	10,758.3	10,494.3	10,880.6	11,413.1	12,313.5
National Science Foundation	4,406.9	4,506.4	6,924.8	6,073.4	5,536.6	5,705.4	5,328.5	5,800.2	5,989.7	6,116.7
Department of Agriculture	2,372.3	2,246.0	2,344.7	2,615.4	2,376.9	2,187.6	2,031.2	2,269.0	2,352.0	2,491.2
Department of Homeland Security	1,106.4	1,056.8	983.6	1,131.8	1,127.5	832.2	718.8	943.8	1,645.2	886.4
Department of Commerce	1,145.4	1,196.4	1,533.4	1,683.2	1,308.9	1,230.7	1,293.9	1,567.8	1,519.4	1,933.0
Department of Transportation	811.0	825.2	846.2	929.2	861.8	936.1	875.8	847.7	884.5	1,095.0
Department of the Interior	624.7	645.3	738.8	728.0	716.5	742.7	717.3	762.4	808.7	850.2
Department of Veterans Affairs	446.5	480.0	510.0	563.0	612.9	614.8	639.0	588.8	661.6	673.4
Environmental Protection Agency	576.0	532.0	552.8	572.3	581.7	581.1	529.7	538.0	520.7	513.3
Department of Education	333.1	328.1	322.4	362.8	346.1	338.0	309.9	322.0	251.3	254.5
Smithsonian Institution	186.0	188.0	226.7	213.0	248.7	246.2	240.3	230.9	229.0	232.6
Agency for International Development	234.5	123.8	160.1	84.3	119.2	77.4	125.5	59.9	212.2	212.2

Agency	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016[a]
Department of Justice	184.4	114.5	103.4	125.4	102.3	85.0	118.7	160.5	149.7	151.5
All other agencies	321.8	272.3	281.8	309.0	357.4	349.0	303.6	300.7	309.6	404.0

[a] FY 2016 data are preliminary and may later be revised.

Note(s)

This table lists all agencies with R&D and R&D plant obligations greater than $100 million in FY 2015. All other agencies include Department of Housing and Urban Development, Department of Labor, Department of State, Department of the Treasury, Appalachian Regional Commission, Consumer Product Safety Commission, Federal Communications Commission, Federal Trade Commission, Library of Congress, National Archives and Records Administration, Nuclear Regulatory Commission, and Social Security Administration.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Survey of Federal Funds for Research and Development.

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The sections immediately following address several topics that illuminate the key recent trends in the important federal role: (1) the ups and downs of overall federal funding for R&D over the last 10 years in particular; (2) how this federal financial support has been distributed across the various federal departments and agencies and by types of performers; (3) which fields of S&E predominate, when looking at federal funding just for research (i.e., basic plus applied research); and, finally, (4) how the U.S. priorities for federal R&D funding compare with those of the world's other large, R&D-performing countries. (All amounts and calculations are in current dollars, unless otherwise noted.)

Of note, the corresponding data for federal funding of U.S. R&D cited in Table 4-1 earlier in this chapter are lower. The Table 4-1 numbers are based on performers' reports of their R&D expenditures from federal funds. This difference between performer and source of funding reports of the level of R&D expenditures has been present in the U.S. data for more than 20 years and reflects various technical issues in the measurement of R&D performance and funding (Appendix Table 4-20). For a discussion, see sidebar Tracking R&D Expenditures: Disparities in the Data Reported by Performers and Sources of Funding.

SIDEBAR

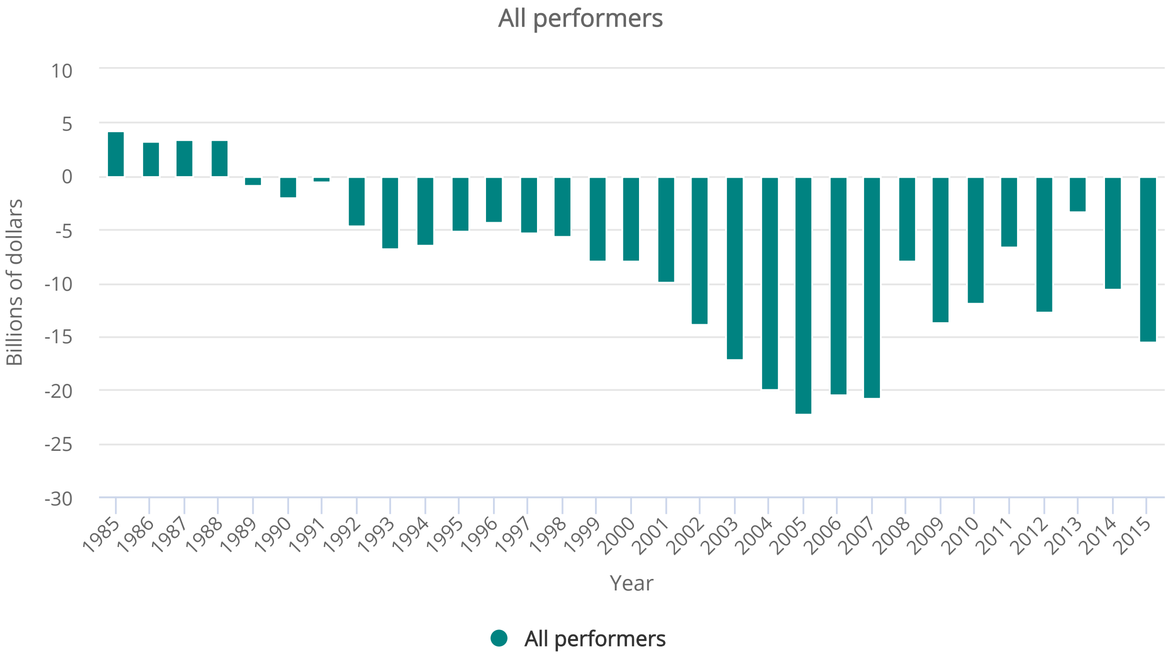
Tracking R&D Expenditures: Disparities in the Data Reported by Performers and Sources of Funding

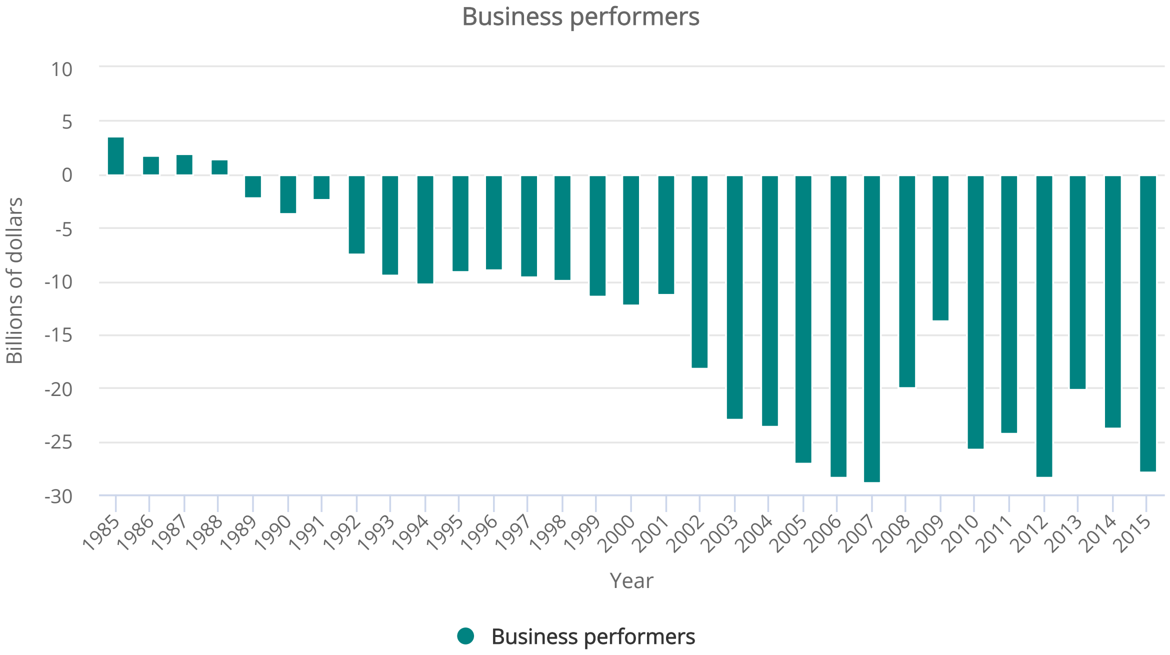
The data on government funding of R&D as reported by the government often differ from those reported by performers of R&D. Consistent with international guidelines, most countries report their national R&D expenditures based chiefly on data from R&D performers (OECD 2015). In the United States, over the last several decades, a sizable gap has opened between what the federal government and R&D performers separately report as the level of federally funded R&D (Figure 4-A; Appendix Table 4-20).

In the mid- to late 1980s, the total of federally funded R&D reported by all U.S. performers exceeded by $3–$4 billion (i.e., 6%–9% of the federally reported total) what the federal government said it funded (top panel of Figure 4-A). In 1989–91, however, the pattern reversed, with the performer-reported total of federal funding less than the federally reported total by $1–$2 billion annually. From the early 1990s through the mid-2000s, this federal report excess grew larger. In 2007, the federal report indicated $127 billion of federal funding for R&D, compared with R&D performers' report of $107 billion—a difference of almost $21 billion, or 16% of the federally reported total. As implied by Figure 4-A's bottom panel (which focuses on only business R&D performers), much of the disparity arose from differences in the federal and performer reports regarding business R&D.

FIGURE 4-A

Difference in federal R&D support, as reported by performers and federal agencies: 1985–2015





Note(s)

Difference is defined as performer-reported R&D minus federally reported R&D funding. A negative discrepancy indicates that agency-reported R&D funding exceeds performer-reported R&D.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, National Patterns of R&D Resources (annual series), and Survey of Federal Funds for Research and Development. See Appendix Table 4-20.

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More recently, the all-performer gap has narrowed, although only to a degree. In 2015, the federal report showed federal funding for all R&D performers exceeding the performer-reported total by $15 billion (12% of the federal report). Furthermore, the federal report excess for only the business R&D performers in these most recent years has remained quite sizable (see Figure 4-A). The appearance is that the federal report now includes lower estimates of the level of federally funded R&D by performers (notably in higher education and the federally funded R&D centers) other than the business sector, which then offset the federal report's higher estimates of funding for business R&D.

Federal R&D funding data are normally reported as obligations on a fiscal year basis; performers typically report R&D expenditures on a calendar year basis. Some of the observed discrepancies reflect this difference in reporting calendars. Nevertheless, adjusting these two data series to a common calendar does not substantially remove the observed gaps.

Several investigations into the possible causes for these data disparities have produced insights but no conclusive explanation. A General Accounting Office investigation made the following assessment:

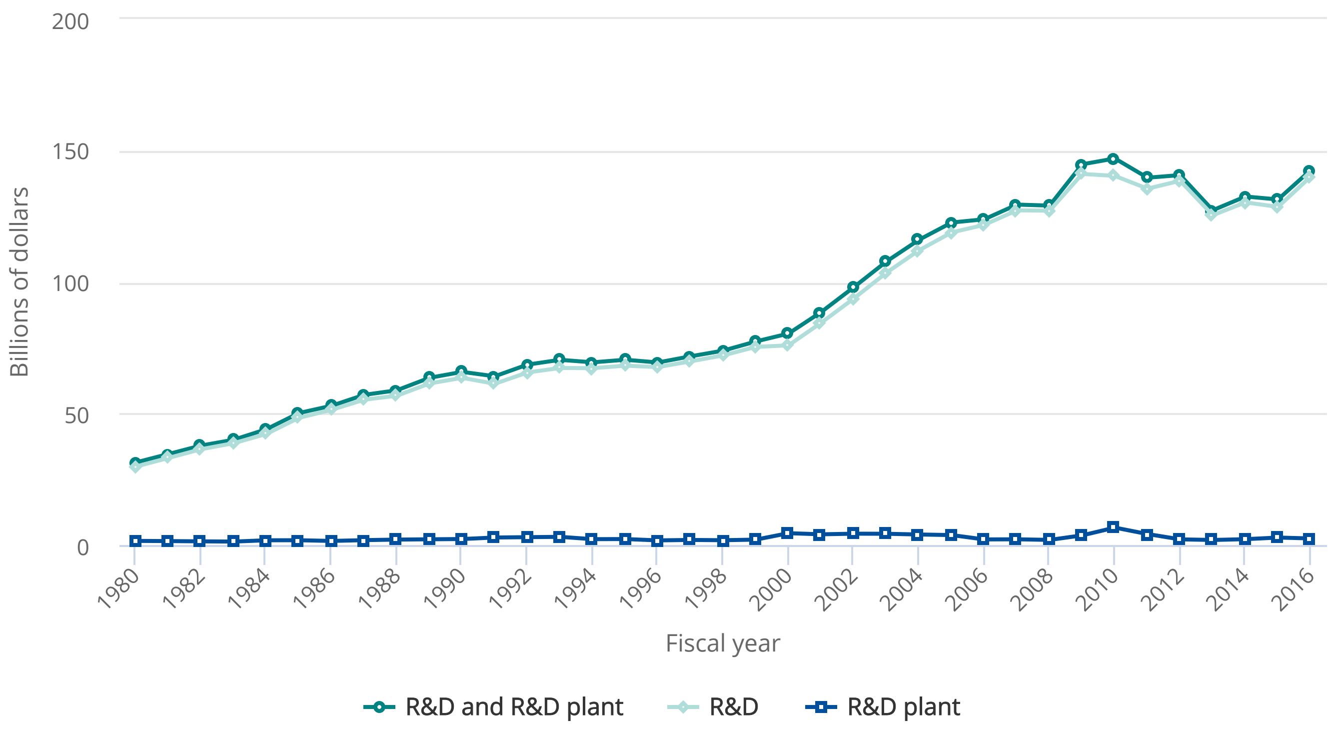
Because the gap is the result of comparing two dissimilar types of financial data (federal obligations and performer expenditures), it does not necessarily reflect poor quality data, nor does it reflect whether performers are receiving or spending all the federal R&D funds obligated to them. Thus, even if the data collection and reporting issues were addressed, a gap would still exist (GAO 2001:2).

Total of Federal Funding for R&D and for Major Agencies

The level of overall federal support for R&D (including for both R&D conduct and R&D plant) has generally increased year to year since the early 1950s (Figure 4-8; Appendix Table 4-21 and Appendix Table 4-22).[1] What was $2–$5 billion in the mid-1950s increased to well above $100 billion in FY 2003 and to just under $130 billion in FYs 2007 and 2008. The level moved higher still in FYs 2009 and 2010, largely a result of the $18.7 billion of incremental funding for R&D authorized by ARRA. In fact, the FYs 2009 and 2010 levels were the highest since the early 1950s, whether considered in current or constant dollar terms (Figure 4-9). Annual growth in federal funding averaged 6.2% in current dollars over FYs 2000–10, or 4.0% when adjusted for inflation.

FIGURE 4-8

Federal obligations for R&D and R&D plant: FYs 1980–2016



Note(s)

FY 2016 data are preliminary and may later be revised. Data for FYs 2009 and 2010 include obligations from the additional federal R&D funding appropriated by the American Recovery and Reinvestment Act of 2009.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Survey of Federal Funds for Research and Development.

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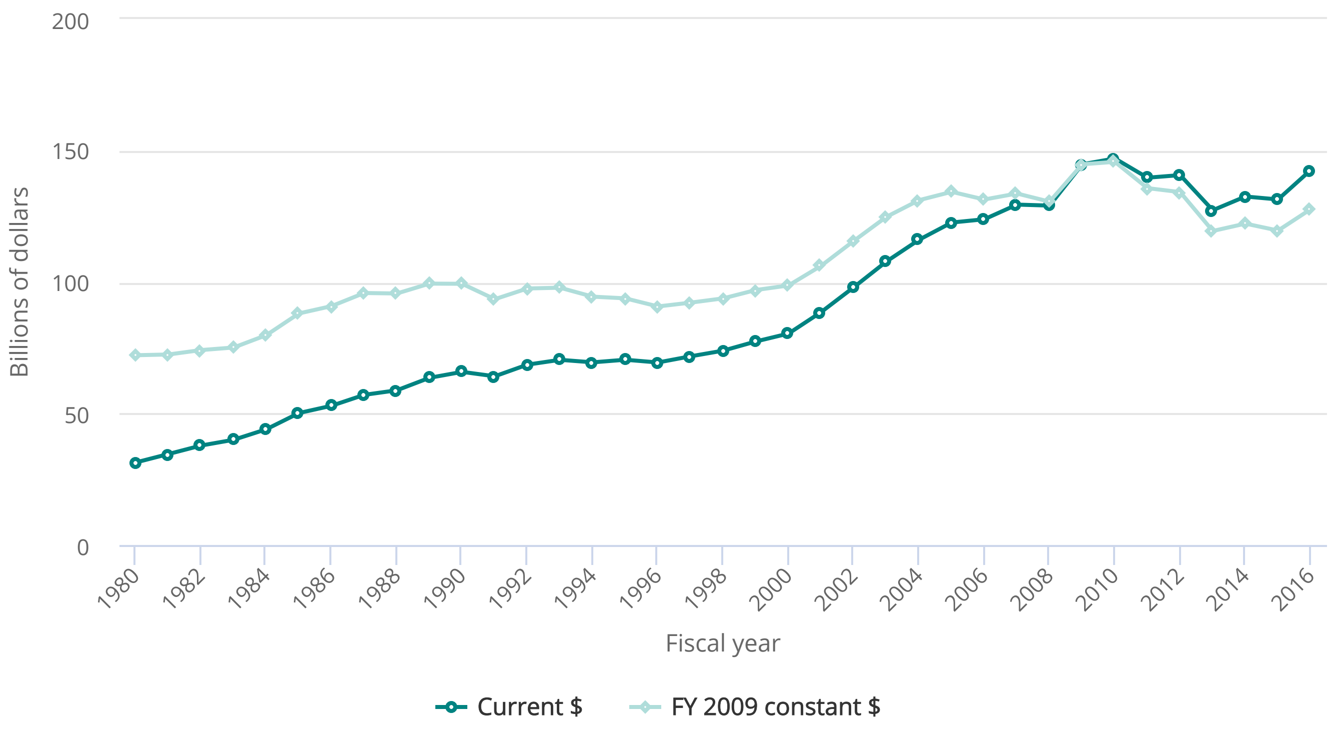
However, a notably different trend has prevailed in the years since then, as federal R&D funding has been buffeted by the more challenging policymaking circumstances for the federal budget that prevailed over the last several years. The $147.0 billion in FY 2010 had dropped to $131.4 billion in FY 2015—with the track of the annual total over the intervening years a mix of several large declines (FYs 2011 and 2013), a modest gain (FY 2014), and several small changes (FYs 2012 and 2015) (Figure 4-9). The obligations total for FY 2016, which is not yet final, indicates a large increase over the FY 2015 level, to $142.6 billion. Nevertheless, when adjusted for inflation, the FY 2015 level is 18% below the FY 2010 level, and the FY 2016 level is still 12% below (Figure 4-9).

FIGURE 4-9

Federal obligations for R&D and R&D plant, current versus constant dollars: FYs 1980–2016



Note(s)

FY 2016 data are preliminary and may later be revised. Data for FYs 2009 and 2010 include obligations from the additional federal R&D funding appropriated by the American Recovery and Reinvestment Act of 2009.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Survey of Federal Funds for Research and Development.

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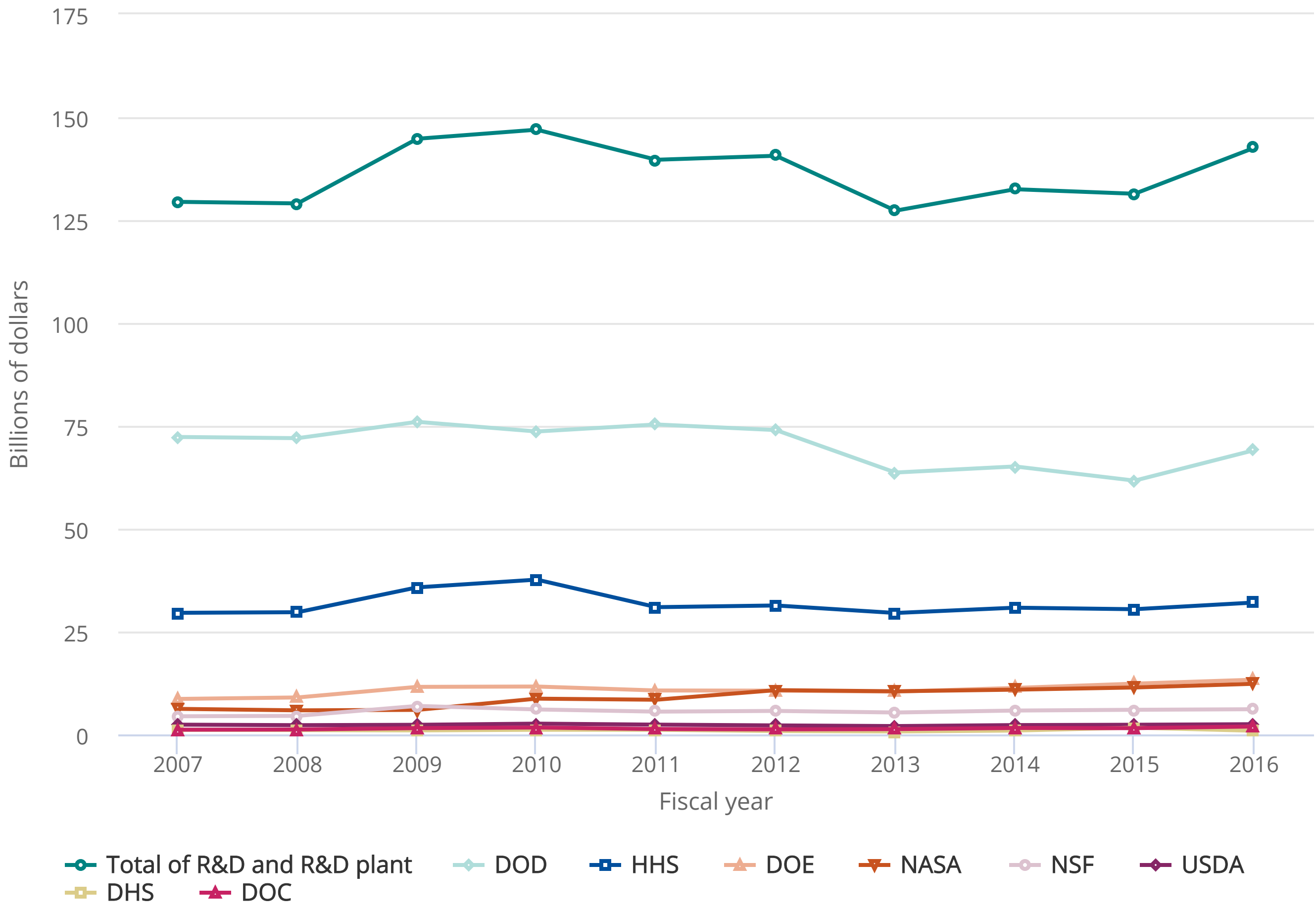
Some of this post–FY 2010 drop in federal R&D funding reflects the waning of the incremental funding provided by ARRA, which showed up as R&D obligations mainly in FYs 2009 and 2010. Even so, the still-sluggish U.S. economy and the more recent federal budget environment since 2011 have taken a toll—with federal funding for R&D affected as part of this larger picture.[2]

In FY 2015, eight agencies each obligated more than $1 billion (current dollars) annually: DOD, HHS, NASA, DOE, NSF, USDA, DHS, and DOC (▦ Table 4-15). Taken together, these eight agencies accounted for about 97% of the federal R&D and R&D plant total that year. Another four agencies obligated funding in the $500 million to $900 million range: Department of Transportation, Department of the Interior, Department of Veterans Affairs, and the Environmental Protection Agency.

📊 Figure 4-10 charts the annual total federal funding for R&D and R&D plant together and that for each of the eight agencies from FY 2007 to FY 2016. With only preliminary data for FY 2016 available at this point, one noticeable trend in the chart is the substantial drop in the federal funding total (current dollars) that occurred from the FY 2010 peak through FY 2015. The figure also shows the funding drop has been borne most heavily by DOD ($11.9 billion of the $15.6 billion cumulative decline from FY 2010 to FY 2015) and HHS ($7.2 billion of the $15.6 decline). NASA had a gain of $2.7 billion over the period; DOE and DHS had gains of, respectively, $0.6 billion and $0.5 billion. The other agencies sustained substantially smaller losses or gains.

FIGURE 4-10

Federal obligations for R&D and R&D plant, by selected agencies: FYs 2007–16



DOC = Department of Commerce; DOD = Department of Defense; DOE = Department of Energy; HHS = Department of Health and Human Services; NASA = National Aeronautics and Space Administration; NSF = National Science Foundation; USDA = Department of Agriculture.

Note(s)

The departments and agencies included in this figure each had annual R&D obligations of $1 billion or more and together account for the vast majority of the R&D and R&D plant total. Data for FYs 2009 and 2010 include obligations from the additional federal R&D funding appropriated by the American Recovery and Reinvestment Act of 2009.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Survey of Federal Funds for Research and Development (annual series).

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Distribution of Federal Funding of R&D, by Performer and Type of Work

Table 4-16 and Table 4-17 provide breakdowns, by agency, of the $131.4 billion of federal dollars obligated for R&D and R&D plant in FY 2015 according to purpose (R&D conduct, R&D plant), performers funded (intramural, extramural), and type of work (basic research, applied research, development).

The majority of federal dollars obligated for R&D ($128.6 billion) was for R&D conduct, whether performed by the intramural R&D facilities of the agencies themselves, agency-affiliated FFRDCs, or by one or more of various other extramural performers receiving federal R&D funding private businesses, universities and colleges, state and local governments, other nonprofit organizations, or foreign performers) (Table 4-16). Barely 2% of the annual total ($2.8 billion) funded R&D plant, with most of the obligations in this category coming from a few agencies.

For the $128.6 billion of obligations for R&D in FY 2015, 25% was for basic research, 25% for applied research, and 50% for development (Table 4-17). These proportions vary widely, however, across the differing departments/agencies.

TABLE 4-16

Federal obligations for R&D and R&D plant, by agency and performer: FY 2015

(Millions of dollars)

Agency	Total	R&D	R&D plant	Total by performers			
				Intramural and FFRDCs	Percentage of total	Extramural performers	Percentage of total
All agencies	131,398.2	128,573.2	2,825.1	48,149.9	36.6	83,248.4	63.4
Department of Defense	61,683.0	61,513.5	169.5	22,241.4	36.1	39,441.6	63.9
Department of Health and Human Services	30,425.5	30,272.1	153.4	7,258.0	23.9	23,167.5	76.1
Department of Energy	12,343.0	11,391.0	952.0	8,640.4	70.0	3,702.6	30.0
National Aeronautics and Space Administration	11,413.1	11,360.7	52.4	3,229.8	28.3	8,183.3	71.7
National Science Foundation	5,989.7	5,669.7	320.0	341.5	5.7	5,648.2	94.3
Department of Agriculture	2,352.0	2,341.0	10.9	1,517.7	64.5	834.3	35.5
Department of Homeland Security	1,645.2	742.2	902.9	1,367.2	83.1	277.9	16.9
Department of Commerce	1,519.4	1,331.3	188.1	1,141.1	75.1	378.3	24.9
Department of Transportation	884.5	855.6	28.9	298.4	33.7	586.0	66.3
Department of the Interior	808.7	800.1	8.6	692.2	85.6	116.4	14.4
Department of Veterans Affairs	661.6	661.6	0.0	661.6	100.0	0.0	0.0
Environmental Protection Agency	520.7	515.6	5.1	261.8	50.3	258.9	49.7
Department of Education	251.3	251.3	0.0	10.7	4.2	240.7	95.8
Smithsonian Institution	229.0	195.7	33.2	229.0	100.0	0.0	0.0
Agency for International Development	212.2	212.2	0.0	10.9	5.1	201.3	94.8
Department of Justice	149.7	149.7	0.0	20.4	13.7	129.3	86.3
All other agencies	309.6	309.6	0.0	227.8	73.6	81.9	26.5

FFRDC = federally funded research and development center.

Note(s)

This table lists all agencies with R&D obligations greater than $100 million in FY 2015. Detail may not add to total because of rounding. R&D is basic research, applied research, and development and does not include R&D plant. Intramural activities include actual intramural R&D performance and costs associated with planning and administering both intramural and extramural programs by federal personnel. Extramural performers include federally funded R&D performed in the United States and U.S. territories by businesses, universities and colleges, other nonprofit institutions, state and local governments, and foreign organizations. All other agencies include Department of Housing and Urban Development, Department of Labor, Department of State, Department of the Treasury, Appalachian Regional Commission, Consumer Product Safety Commission, Federal Communications Commission, Federal Trade Commission, Library of Congress, National Archives and Records Administration, Nuclear Regulatory Commission, and Social Security Administration.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Survey of Federal Funds for Research and Development, FY 2015–17.

Science and Engineering Indicators 2018

TABLE 4-17

Federal obligations for R&D, by agency and type of work: FY 2015

(Millions of current dollars)

Agency	Total R&D	Basic research	Applied research	Development	Percentage of total R&D		
					Basic research	Applied research	Development
All agencies	128,573.2	31,527.1	32,118.2	64,927.8	24.5	25.0	50.5
Department of Defense	61,513.5	2,133.4	4,558.1	54,822.1	3.5	7.4	89.1
Department of Health and Human Services	30,272.1	15,076.9	15,119.9	75.4	49.8	49.9	0.2
Department of Energy	11,391.0	4,460.4	4,181.1	2,749.5	39.2	36.7	24.1
National Aeronautics and Space Administration	11,360.7	3,209.7	2,329.7	5,821.3	28.3	20.5	51.2
National Science Foundation	5,669.7	4,973.9	695.8	0.0	87.7	12.3	0.0
Department of Agriculture	2,341.0	924.5	1,203.9	212.7	39.5	51.4	9.1
Department of Homeland Security	742.2	11.7	205.1	525.4	1.6	27.6	70.8
Department of Commerce	1,331.3	232.4	921.5	177.4	17.5	69.2	13.3
Department of Transportation	855.6	0.0	662.6	192.9	0.0	77.5	22.5
Department of the Interior	800.1	53.3	627.0	119.7	6.7	78.4	15.0
Department of Veterans Affairs	661.6	227.2	416.3	18.1	34.3	62.9	2.7
Environmental Protection Agency	515.6	0.0	440.4	75.2	0.0	85.4	14.6
Department of Education	251.3	22.4	137.4	91.6	8.9	54.7	36.4
Smithsonian Institution	195.7	195.7	0.0	0.0	100.0	0.0	0.0
Agency for International Development	212.2	0.0	212.2	0.0	0.0	100.0	0.0
Department of Justice	149.7	5.3	123.0	21.3	3.6	82.2	14.3
All other agencies	309.6	0.2	284.2	25.3	0.1	91.8	8.2

Note(s)

This table lists all agencies with R&D obligations greater than $100 million in FY 2015. Detail may not add to total because of rounding. All other agencies include Department of Housing and Urban Development, Department of Labor, Department of State, Department of the Treasury, Appalachian Regional Commission, Consumer Product Safety Commission, Federal Communications Commission, Federal Trade Commission, Library of Congress, National Archives and Records Administration, Nuclear Regulatory Commission, and Social Security Administration.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Survey of Federal Funds for Research and Development, 2015–17.

Science and Engineering Indicators 2018

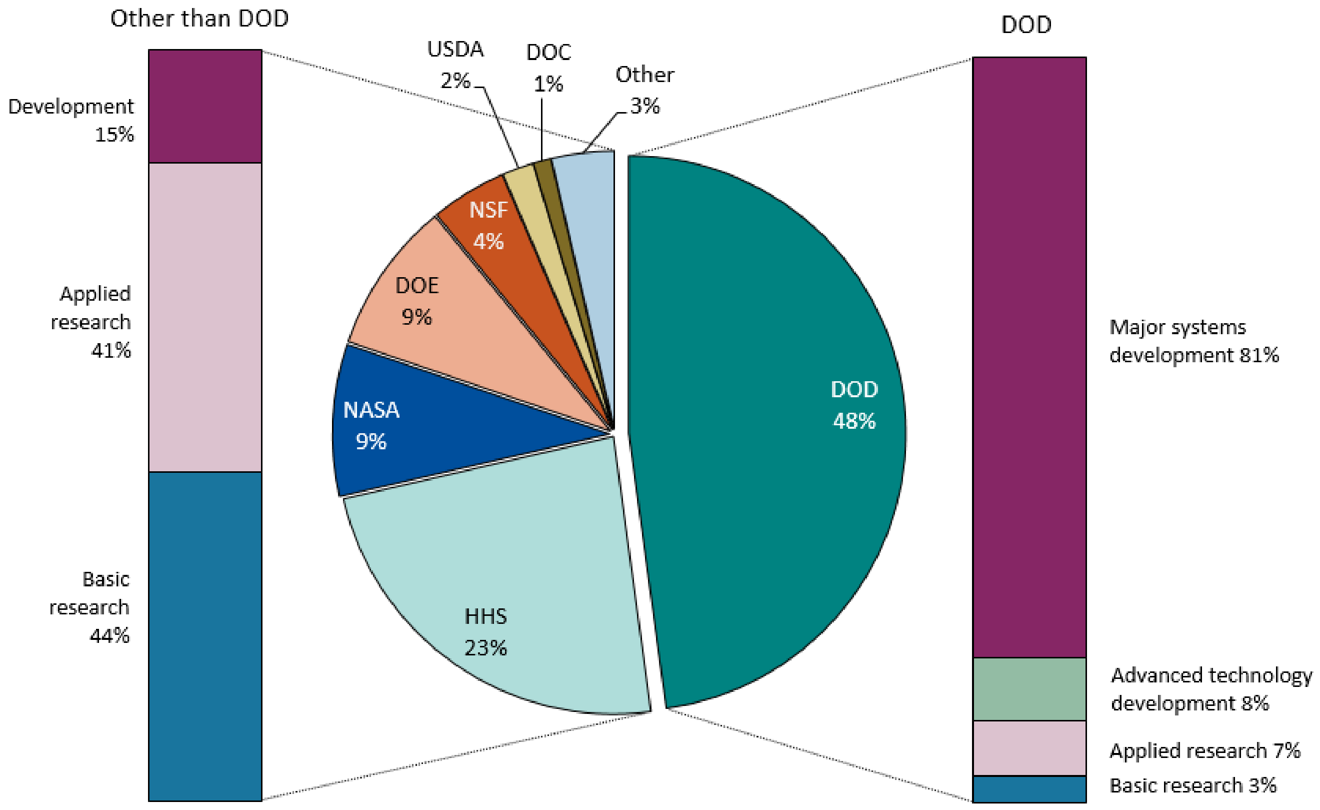
Department of Defense

In FY 2015, DOD obligated a total of $61.7 billion for R&D and R&D plant (Table 4-16), about 47% of all federal R&D and R&D plant spending that year. Almost all of the DOD total was R&D spending ($61.5 billion), with the remainder spent on R&D plant. Of the total, 36% ($22.2 billion) was spending by the department's intramural laboratories, related agency R&D program activities, and FFRDCs (Table 4-16). Extramural performers accounted for 64% ($39.4 billion) of the obligations, with the bulk going to business firms ($35.8 billion) (Appendix Table 4-23).

Considering just the R&D, relatively small amounts were spent on basic research ($2.1 billion, 3%) and applied research ($4.6 billion, 7%) in FY 2015 (Table 4-17). The majority of the obligations, $54.9 billion (89%), went to development. Furthermore, the bulk of this DOD development ($49.6 billion) was allocated for major systems development, which includes the main activities in developing, testing, and evaluating combat systems (Figure 4-11). The remaining DOD development ($5.2 billion) was allocated for advanced technology development, which is more similar to other agencies' development obligations.

FIGURE 4-11

Federal obligations for R&D, by agency and type of work: FY 2015



DOC = Department of Commerce; DOD = Department of Defense; DOE = Department of Energy; HHS = Department of Health and Human Services; NASA = National Aeronautics and Space Administration; NSF = National Science Foundation; USDA = Department of Agriculture.

Note(s)

Detail may not add to total because of rounding.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Survey of Federal Funds for Research and Development.

Science and Engineering Indicators 2018

Department of Health and Human Services

HHS is the main federal source of funds for health-related R&D. In FY 2015, the department obligated $30.4 billion for R&D and R&D plant, or 23% of the total of federal obligations that year. Nearly all the funding was for R&D ($30.3 billion). Furthermore, the majority, $29.0 billion, was for the R&D activities of NIH.

For the department as a whole, R&D and R&D plant obligations for agency intramural activities and FFRDCs accounted for 24% ($7.3 billion) of the total. Extramural performers accounted for 76% ($23.3 billion). Universities and colleges ($16.9 billion) and other nonprofit organizations ($4.3 billion) were the most sizable of these extramural activities (Appendix Table 4-23). Nearly all HHS R&D funding was allocated to research—50% for basic research and 50% for applied research. Only a tiny fraction, 0.2%, was for development.

Department of Energy

DOE obligated $12.3 billion for R&D and R&D plant in FY 2015, or about 9% of the total of federal obligations that year. Of this amount, $11.4 billion was for R&D, and $1.0 billion was for R&D plant.

The department's intramural laboratories and FFRDCs accounted for 70% of the obligations total, a substantially higher percentage than most other agencies. Many of DOE's research activities require specialized equipment and facilities available only at its intramural laboratories and FFRDCs, which are used by scientists and engineers from other agencies and sectors as well as by DOE researchers. The remaining 30% of obligations went to extramural performers, chiefly to businesses and to universities and colleges.

Basic research accounted for 39% of the $11.4 billion obligated to R&D, applied research accounted for 37%, and development accounted for 24%.

DOE R&D activities are distributed among domestic energy systems, defense (much of it funded by the department's National Nuclear Security Administration), and general science (much of which is funded by the department's Office of Science).

National Aeronautics and Space Administration

NASA obligated $11.4 billion to R&D in FY 2015, or around 9% of the federal total. Nearly all of it ($11.4 billion) was for R&D. Of these obligations, 72% were for extramural R&D, which was conducted chiefly by business performers. Agency intramural R&D and that done by FFRDCs represented 28% of the total NASA obligations. By type of R&D, 51% of the NASA R&D obligations funded development activities, 28% funded basic research, and 21% funded applied research.

National Science Foundation

In FY 2015, NSF obligated $6.0 billion for R&D and R&D plant, or 5% of the federal total that year—$5.7 billion for R&D and $0.3 billion for R&D plant. Extramural performers, chiefly universities and colleges, accounted for 94% ($5.6 billion). Basic research was about 88% of the R&D component. NSF is a primary source of federal government funding for academic basic S&E research; it is the second largest federal source (after HHS) of R&D funds for universities and colleges.

Department of Agriculture

USDA obligated $2.4 billion for R&D and R&D plant in FY 2015 (2% of the federal total), focusing mainly on life sciences. The agency is also one of the largest research funders in the social sciences, particularly agricultural economics. Of USDA's total obligations for FY 2015, about 65% ($1.5 billion) funded R&D by agency intramural performers, chiefly the Agricultural Research Service. Basic research accounts for about 39% of the federal total, applied research accounts for 51%, and development accounts for 9%.

Department of Homeland Security

DHS obligated $1.6 billion for R&D in FY 2015 (1% of the federal total), nearly all of which was for R&D ($0.7 billion) and R&D plant ($0.9 billion) spending of the department's Science and Technology Directorate. Of the total, 83% was for agency intramural R&D; 17% went to extramural performers, primarily businesses and universities and colleges. For the R&D component, 2% was for basic research, 28% was for applied research, and 71% was for development.

Department of Commerce

DOC obligated $1.5 billion for R&D in FY 2015 (about 1% of the federal total), most of which represented R&D ($1.3 billion) and R&D plant ($0.2 billion) spending of the National Oceanic and Atmospheric Administration and the National Institute of Standards and Technology. Of this total, 75% was for agency intramural R&D; 25% went to extramural performers, primarily universities and colleges. For the R&D component, 17% was for basic research, 69% was for applied research, and 13% was for development.

Other Agencies

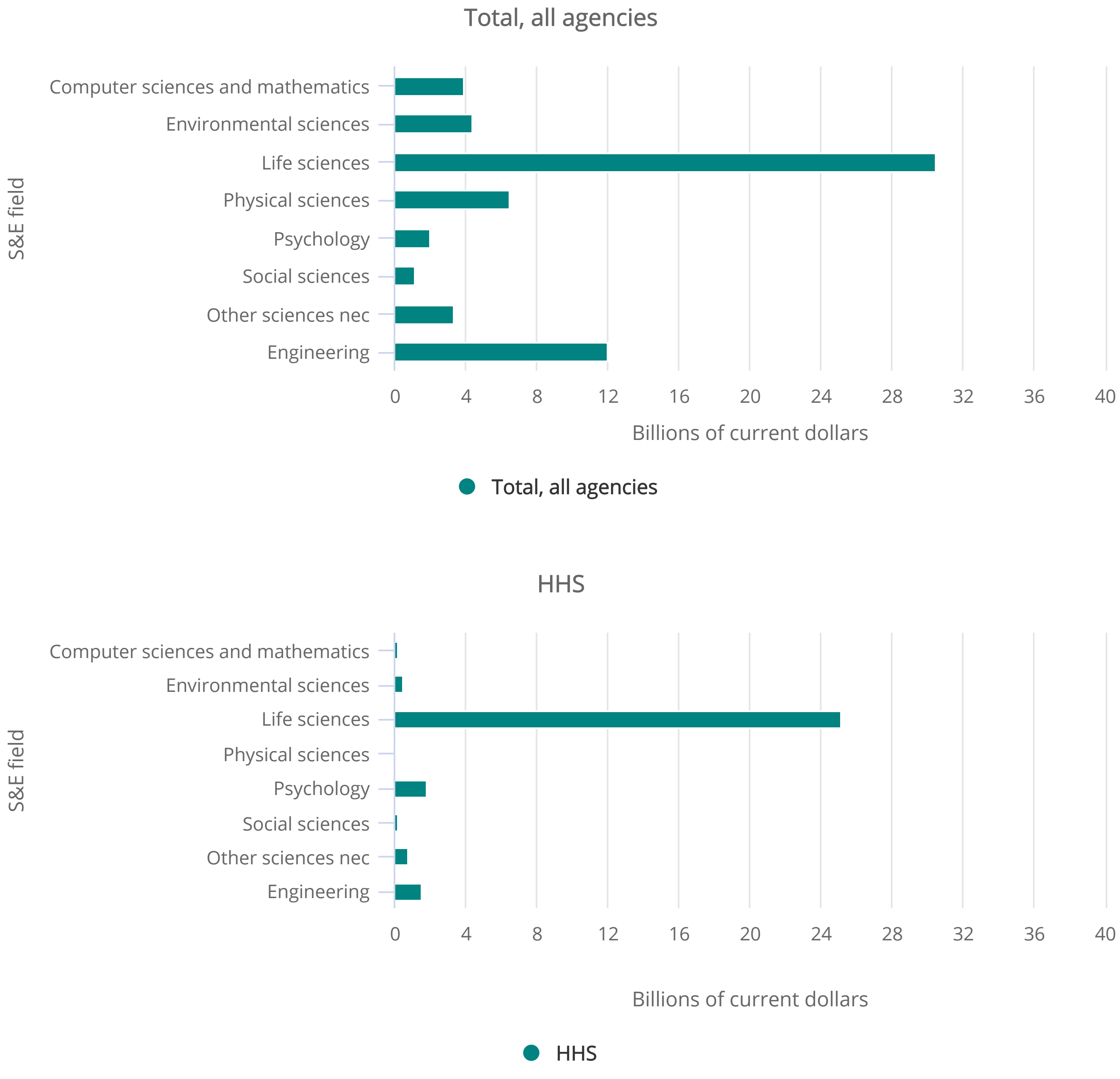
The eight agencies already discussed accounted for 97% of the total R&D and R&D plant obligations ($131.4 billion) in FY 2015. The other agencies shown in Table 4-16 and Table 4-17 play significant roles in the overall U.S. R&D system, but individually they account for comparatively small to very small levels of federal resources annually. Furthermore, as the data in the tables show, these agencies continue to vary considerably with respect to the type of research and the roles of intramural, FFRDC, and extramural performers.

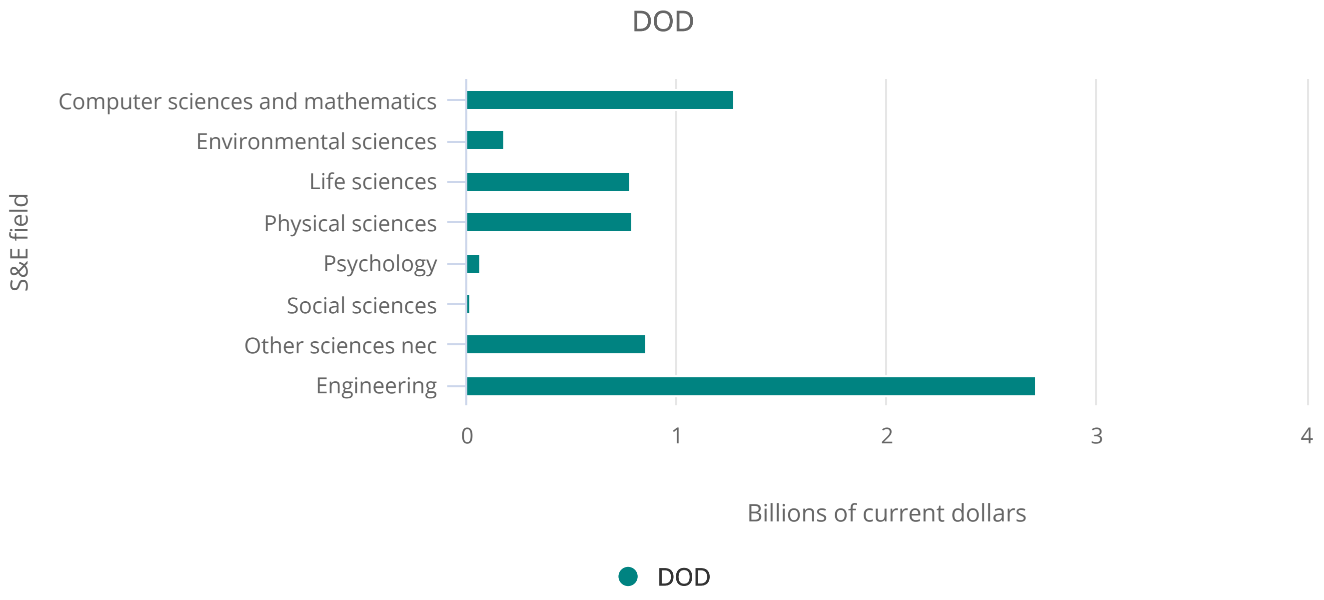
Distribution of Federal Funding for Research, by S&E Fields

Development work cannot easily be classified by S&E field, but research—basic and applied—can be. The research conducted and/or funded by the federal government spans a full range of S&E fields (computer sciences and mathematics, environmental sciences, life sciences, physical sciences, psychology, social sciences, engineering, and other S&E fields). Analysis of the source, nature, and field support patterns provides insights into the federal government's research priorities (Figure 4-12; Appendix Table 4-24 and Appendix Table 4-25).

FIGURE 4-12

Federal obligations for research, by agency and major S&E field: FY 2015




DOD
S&E field
Computer sciences and mathematics
Environmental sciences
Life sciences
Physical sciences
Psychology
Social sciences
Other sciences nec
Engineering
0
1
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Billions of current dollars
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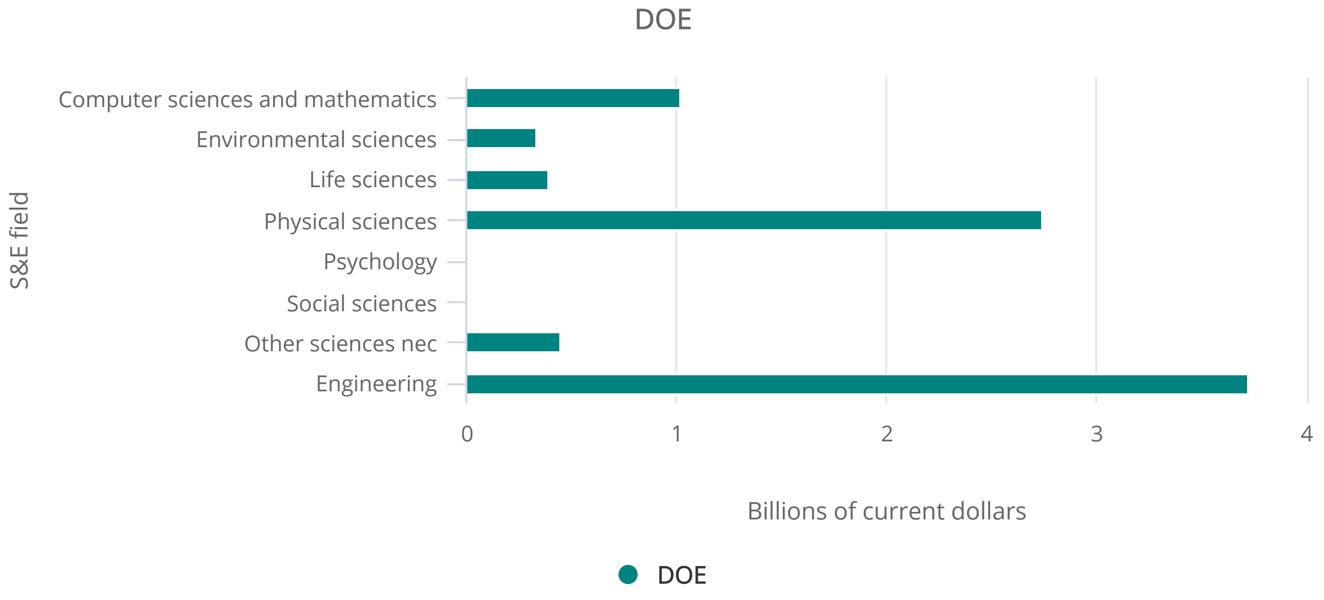
DOE
S&E field
Computer sciences and mathematics
Environmental sciences
Life sciences
Physical sciences
Psychology
Social sciences
Other sciences nec
Engineering
0
1
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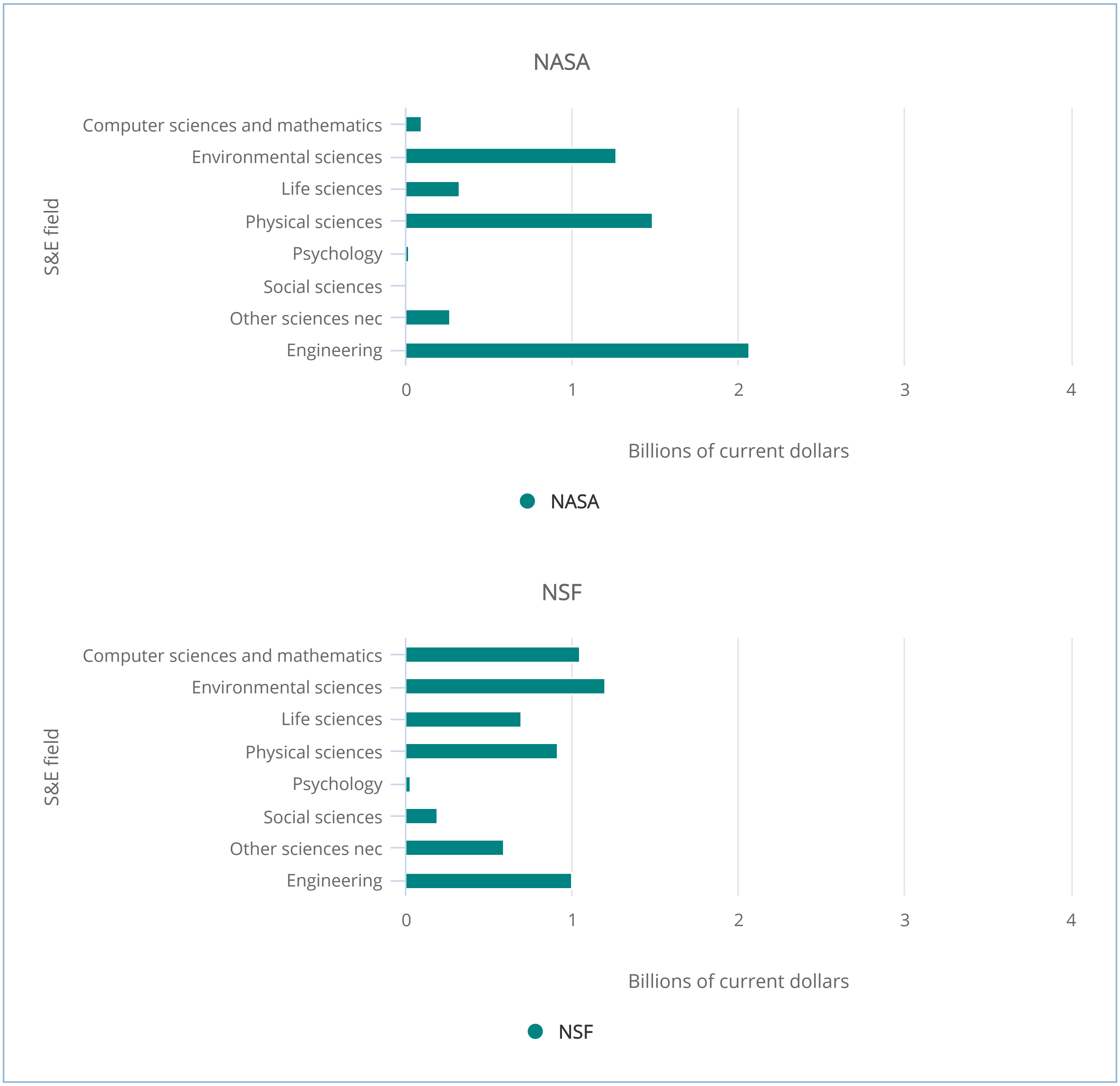
4
Billions of current dollars
● DOE


NASA
S&E field
Computer sciences and mathematics
Environmental sciences
Life sciences
Physical sciences
Psychology
Social sciences
Other sciences nec
Engineering
0
1
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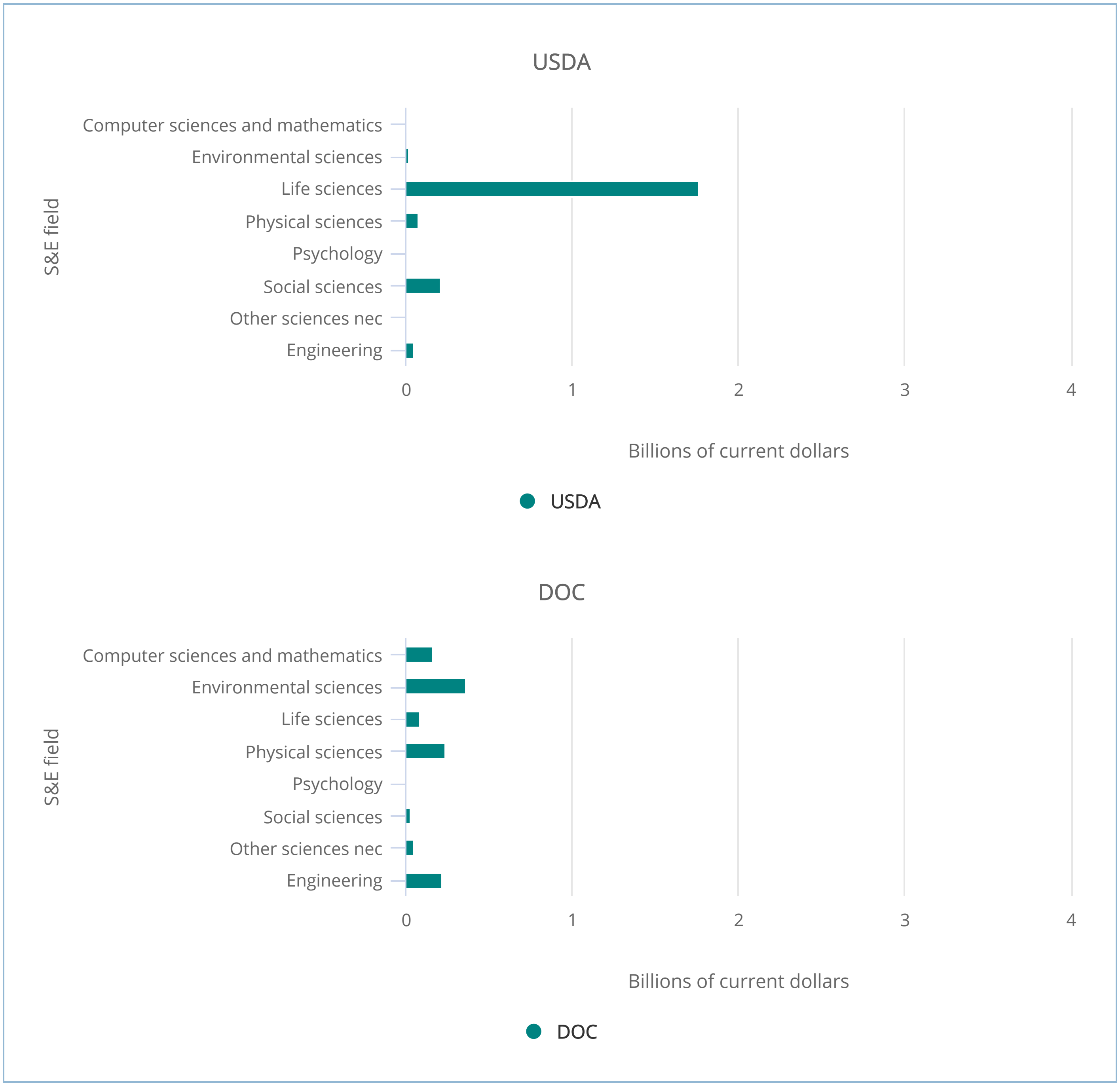
4
Billions of current dollars
● NASA
NSF
S&E field
Computer sciences and mathematics
Environmental sciences
Life sciences
Physical sciences
Psychology
Social sciences
Other sciences nec
Engineering
0
1
2
3
4
Billions of current dollars
● NSF


USDA
S&E field
Computer sciences and mathematics
Environmental sciences
Life sciences
Physical sciences
Psychology
Social sciences
Other sciences nec
Engineering
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Billions of current dollars
USDA
DOC
S&E field
Computer sciences and mathematics
Environmental sciences
Life sciences
Physical sciences
Psychology
Social sciences
Other sciences nec
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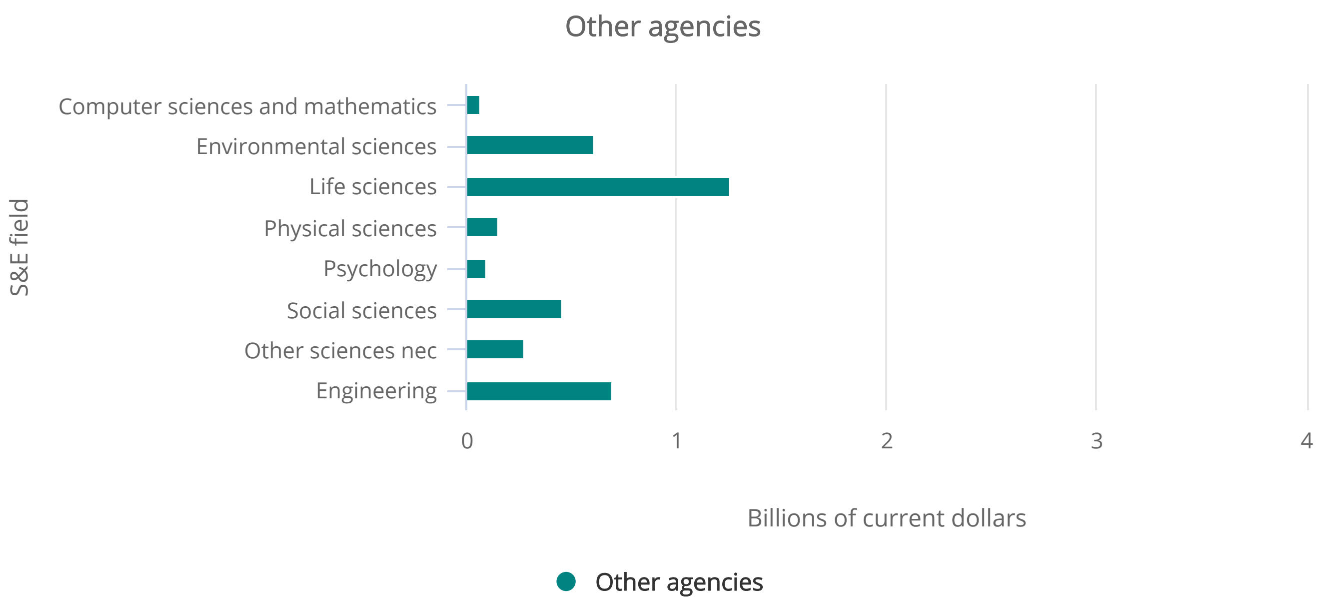
Billions of current dollars
DOC



DOC = Department of Commerce; DOD = Department of Defense; DOE = Department of Energy; HHS = Department of Health and Human Services; NASA = National Aeronautics and Space Administration; nec = not elsewhere classified; NSF = National Science Foundation; USDA = Department of Agriculture.

Note(s)

The scales differ for total, all agencies, and HHS compared with the scales for the other agencies listed. Research includes basic and applied research.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Survey of Federal Funds for Research and Development, FYs 2015–17 . See Appendix Table 4-24.

Science and Engineering Indicators 2018

In FY 2015, funding for basic and applied research combined accounted for half ($63.6 billion) of the $128.6 billion total of federal obligations for R&D (▦ Table 4-17). About half of this amount, $30.5 billion, supported research in the life sciences (Appendix Table 4-24). The fields with the next largest amounts were engineering ($12.0 billion, 19%) and physical sciences ($6.5 billion, 10%), followed by environmental sciences ($4.4 billion, 7%) and computer sciences and mathematics ($3.7 billion, 6%). The balance of federal obligations for research in FY 2015 supported psychology, social sciences, and all other sciences ($6.4 billion overall, or 10% of the total for research).

The allocation of federal research funds across agencies and fields reflect the differing agency missions. HHS accounted for the largest share (47%) of federal obligations for research in FY 2015 (Appendix Table 4-24). Most of this amount funded research in life sciences, primarily through NIH. The six next largest federal agencies for research funding that year were DOE (14%), DOD (11%), NSF (9%), NASA (9%), USDA (3%), and DOC (2%).

DOE's $8.6 billion in research obligations provided funding for research primarily in engineering ($3.7 billion), physical sciences ($2.7 billion), and computer sciences and mathematics ($1.0 billion). DOD's $6.7 billion of research funding emphasized engineering ($2.7 billion) but also included computer sciences and mathematics ($1.2 billion), physical sciences ($0.8 billion), and life sciences ($0.8 billion). NSF is charged with "promoting the health of science." As such, it had a comparatively diverse $5.7 billion research portfolio that allocated about $0.7 billion to $1.2 billion in each of the following fields: environmental sciences, life sciences, computer sciences and mathematics, physical sciences, and engineering. Lesser amounts were allocated to psychology, social sciences, and other sciences. NASA's $5.5 billion for research emphasized engineering ($2.1 billion), followed by physical sciences ($1.5 billion) and environmental sciences ($1.3 billion). USDA's $2.1 billion was directed primarily at life (agricultural) sciences ($1.8 billion). DOC's $1.1 billion was distributed mainly in the fields of environmental sciences, physical sciences, engineering, and computer sciences and mathematics.

Viewed over the longer time span of 1990 to 2015, the total of federal funds obligated for research across all S&E fields increased on average by 5.9% annually over 1990–2000 and by 5.2% over 2000–10 (Appendix Table 4-25). Adjusted for inflation, these average annual growth rates were, respectively, 3.8% and 3.0%. More recently, however, the research obligations total has been declining—essentially a zero average annual rate of growth for the period of FYs 2010–15, or -1.7% when adjusted for inflation (Appendix Table 4-25).

A more complex mix of trends is evident when narrowly defined S&E fields are considered. Federally funded research in the environmental sciences increased by an inflation-adjusted average annual rate of 3.9% in FYs 2010–15, reversing a sizable constant dollar decline in FYs 2000–10 (Appendix Table 4-25). In contrast, federally funded research in life sciences showed a constant dollar, average annual decline of 3.8% over the same period, reversing what were high positive rates of growth through the decade of the 1990s and 2000–10. Federally funded research in computer sciences and mathematics averaged 0.8% in FYs 2010–15, well ahead of the decline that prevailed for all S&E fields together, but the rate was well below those for the 1990s and 2000–10. The rate for physical sciences also was above zero for FYs 2010–15, reversing lower rates in the earlier periods. Engineering showed a declining average annual rate for FYs 2010–15, reversing what were notably positive growth rates in the earlier periods. Other fields (e.g., psychology, social sciences) showed constant dollar declines in the FY 2010–15 period, worse than that for the all-fields total.

Cross-National Comparisons of Government R&D Priorities

Government R&D funding statistics compiled annually by the OECD provide insights into how national government priorities for R&D differ across countries. Known technically as government budget allocations for R&D (GBARD), this indicator provides data on how a country's overall government funding for R&D splits among a set of socioeconomic categories (e.g., defense, health, space, general research).[3] GBARD statistics are available for the United States and most of the other top R&D-performing countries discussed earlier in ▦Table 4-18 (corresponding GBARD data for China and India are not currently available). (All amounts and calculations are in current purchasing power parity or PPP dollars, unless otherwise noted.)

Defense is an objective for government funding of R&D for all the top R&D-performing countries, but the shares vary considerably (▦Table 4-18). Defense accounted for 51% of U.S. federal R&D support in 2015 but was markedly lower elsewhere—a smaller but still sizable 16% in the United Kingdom, 14% in South Korea, 7% in France, and 3%–4% in Germany and Japan.

TABLE 4-18

Government R&D support by major socioeconomic objectives, by selected countries or regions and years: Selected years, 2000–15

(Millions of U.S. dollars and percent)

Region or country	Year	GBARD (current PPP US$millions)	Percentage of GBARD		Percentage of nondefense					
			Defense	Nondefense	Economic development programs	Health and environment	Education and society	Civil space	Non-oriented research	General university funds
United States	2000	83,612.5	51.6	48.4	13.4	49.9	1.8	20.9	13.8	na
	2010	148,962.0	57.3	42.7	12.5	56.1	1.6	12.9	16.9	na
	2015	138,544.0	51.4	48.6	11.7	52.6	3.0	16.2	16.5	na
EU	2000	76,650.9	12.6	87.4	23.3	11.6	3.4	6.0	17.8	35.0
	2010	117,880.8	6.4	93.6	22.2	14.1	6.5	5.3	18.2	33.1
	2015	125,477.4	4.4	95.6	20.5	14.8	5.5	5.2	18.7	35.4
France	2000	14,868.7	21.4	78.5	17.7	9.7	1.1	13.2	27.4	28.5
	2010	19,178.6	14.7	85.3	21.1	12.6	5.3	12.7	19.6	27.0
	2015	17,721.1	7.2	92.8	17.8	12.5	5.9	11.3	22.8	27.6
Germany	2000	17,228.7	7.8	92.2	21.6	9.4	3.9	5.1	17.5	42.4
	2010	28,642.4	5.0	95.0	24.4	9.2	4.4	5.0	17.0	40.6
	2015	34,301.9	3.1	96.9	21.8	10.2	4.7	5.2	18.0	41.7
United Kingdom	2000	9,484.9	35.6	64.4	14.2	27.7	6.3	3.4	18.3	29.7

Region or country	Year	GBARD (current PPP US$millions)	Percentage of GBARD		Percentage of nondefense					
			Defense	Nondefense	Economic development programs	Health and environment	Education and society	Civil space	Non-oriented research	General university funds
	2010	13,341.6	18.2	81.8	8.5	32.3	5.0	2.1	22.0	30.1
	2015	14,696.1	16.4	83.6	15.8	35.1	5.1	4.0	13.8	26.2
Japan	2000	21,193.4	4.1	95.9	33.4	6.6	1.0	5.8	14.6	37.0
	2010	32,149.0	4.8	95.2	27.6	7.4	0.9	7.1	21.0	35.9
	2015	33,907.4	4.4	95.6	24.7	6.9	0.7	6.5	23.0	38.2
South Korea	2000	5,017.9	20.5	79.5	53.4	14.8	3.8	3.1	24.9	**
	2010	16,300.1	13.3	86.7	52.1	13.7	2.4	2.7	29.1	**
	2015	21,207.5	13.5	86.5	50.3	14.7	7.8	3.1	24.1	**

** = included in other categories. na = not applicable; country or region does not use this funding mechanism.

EU = European Union; GBARD = government budget appropriations or outlays for R&D; PPP = purchasing power parity.

Note(s)

Foreign currencies are converted to dollars through PPPs. The GBARD statistics reported for the United States are federal budget authority data. GBARD data are not yet available for China or India. The socioeconomic objective categories are aggregates of the 14 categories identified by Eurostat's 2007 Nomenclature for the Analysis and Comparison of Scientific Programmes and Budgets. The data are as reported by the Organisation for Economic Co-operation and Development (OECD).

Source(s)

OECD, *Main Science and Technology Indicators* (2017/1).

Science and Engineering Indicators 2018

Defense has received 50% or more of the federal R&D budget in the United States for many years. The defense share was 63% in 1990 as the Cold War period waned but then dropped in subsequent years. It rose again in the first decade of the 2000s—in large part, reflecting post-9/11 security concerns—but it has been declining again over the last several years. For the other countries, the defense share of government R&D funding has generally declined or remained at a stable, low level.

The health and environment objective accounted for almost 53% of nondefense federal R&D budget support in the United States in FY 2015 and 35% in the United Kingdom. For both countries, the share has expanded markedly over the share prevailing several decades ago. The health and environment share of nondefense government R&D is currently 15% in South Korea and 13% or less in France, Germany, and Japan.

The economic development objective encompasses agriculture, energy, fisheries and forestry, industry, transportation, telecommunications, and other infrastructure. In the United States, government R&D funding in this category was 13% of all nondefense federal support for R&D in 2000 and had dropped to just below 12% in 2015, substantially lower than most other major nations (Table 4-18).[4] In the United Kingdom, government R&D funding for economic development was at 14% in 2000, declining from 2000 to 2010 but rising to 16% in 2015. France was at 18% in 2000, rising to 21% by 2010, but declining back to 18% by 2015. Japan was at 33% in 2000 but generally declined in the years after to 25% in 2015. Germany was at 22% in 2000, rising somewhat by 2010, but dropping back to 22% in 2015. South Korea, at 52% in 2010 and 50% in 2015, has consistently exhibited the largest share for this category among the top R&D-performing countries.

The civil space objective accounted for about 16% of nondefense federal R&D funding in the United States in 2015 (Table 4-18). The share was 21% in 2000 and declined to 13% by 2010 but has experienced increases more recently. The share in France was about 11% for 2015, down from 13% in both 2000 and 2010. The space share has been well below 10% for the rest of the top R&D-performing countries.

Both the nonoriented research funding and general university fund (GUF) objectives reflect government support for R&D by academic, government, and other performers that is directed chiefly at the "general advancement of knowledge" in the natural sciences, engineering, social sciences, humanities, and related fields. For some of the countries, the sum of these two objectives represents by far the largest part of nondefense GBARD: in 2015, Japan (61%), Germany (60%), France (50%), the United Kingdom (40%), and South Korea (24%). The corresponding 2015 share for the United States (17%), although appearing substantially smaller, requires interpretive caution. Cross-national comparisons of these particular indicators can be difficult because some countries (notably the United States) do not use the GUF mechanism to fund R&D for general advancement of knowledge, do not separately account for GUF (e.g., South Korea), and/or more typically direct R&D funding to project-specific grants or contracts, which are then assigned to the more specific socioeconomic objectives (see sidebar Government Funding Mechanisms for Academic Research).

SIDEBAR

Government Funding Mechanisms for Academic Research

U.S. universities generally do not maintain data on departmental research (i.e., research that is not separately budgeted and accounted for). As such, U.S. R&D totals are understated relative to the R&D effort reported for many other countries. The national totals for Europe, Canada, and Japan include the research component of general university fund (GUF) block grants provided by all levels of government to the academic sector. These funds can support departmental R&D programs that are not separately budgeted. GUF is not equivalent to basic research. The U.S. federal government does not provide research support through a GUF equivalent, preferring instead to support specific, separately budgeted R&D projects. However, some state government funding probably does support departmental research, not separately accounted for, at U.S. public universities.

The treatment of GUF is one of the major areas of difficulty in making international R&D comparisons. In many countries, governments support academic research primarily through large block grants that are used at the discretion of each higher education institution to cover administrative, teaching, and research costs. Only the R&D component of GUF is included in national R&D statistics, but problems arise in identifying the amount of the R&D component and the objective of the research. Moreover, government GUF support is in addition to support provided in the form of earmarked, directed, or project-specific grants and contracts (funds that can be assigned to specific socioeconomic categories).

In several large European countries (France, Germany, Italy, and the United Kingdom), GUF accounts for 50% or more of total government R&D funding to universities. In Canada, GUF accounts for about 38% of government academic R&D support. Thus, international data on academic R&D reflect not only the relative international funding priorities but also the funding mechanisms and philosophies regarded as the best methods for financing academic research.

Finally, the education and society objective represents a comparatively small component of nondefense government R&D funding for all the top R&D-performing countries—3% of nondefense GBARD in the United States in 2015. However, the share was notably higher in South Korea (8%), France (6%), Germany (5%), and the United Kingdom (5%). Japan (1%) was well below the United States.

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[1] The analysis in this section focuses primarily on developments in federal R&D priorities and funding support over the course of the last decade. Nevertheless, there is an important and interesting story to tell about how the comparatively minor federal role in the nation's science and research system up until World War II was reconsidered, redirected, and greatly enlarged, starting shortly after the end of the war and moving through the subsequent decades to the present. For a review of the essential elements of this evolving postwar federal role, see Jankowski (2013).

[2] For a further account of this recent federal budget history, see Boroush (2015, 2016). Notable among the various interconnected developments over these years were the federal-wide spending reductions imposed by the enacted FY 2011 federal budget: the Budget Control Act of 2011, intended to address the then-ongoing national debt ceiling crisis, which commanded a 10-year schedule of budget caps and spending cuts; the budget sequestration provision, which ultimately took hold in the FY 2013 federal budget; and the Bipartisan Budget Act of 2013, which provided some subsequent relief from the deepening sequestration requirements, but only for the FY 2014 and FY 2015 budgets.

[3] GBARD classifies total government funding on R&D into the 14 socioeconomic categories specified by the EU's 2007 edition of the Nomenclature for the Analysis and Comparison of Scientific Programmes and Budgets (NABS). These categories are exploration and exploitation of the earth; environment; exploration and exploitation of space; transport, telecommunications, and other infrastructures; energy; industrial production and technology; health; agriculture; education; culture, recreation, religion, and mass media; political and social systems, structures, and processes; general advancement of knowledge: R&D financed from general university funds; general advancement of knowledge: R&D financed from sources other than general university funds; and defense. GBARD statistics published by the OECD in the *Main Science and Technology Indicators* series report on clusters of these 14 NABS categories. (Prior to the fall of 2015, GBARD was referred to as GBAORD, or government budget authority or outlays for R&D. Earlier data may continue to use the GBAORD terminology.)

[4] Some analysts argue that the relatively low nondefense GBARD share for economic development in the United States reflects the expectation that businesses will finance industrial R&D activities with their own funds. Moreover, government R&D that may be useful to industry is often funded with other purposes in mind, such as defense and space, and then classified in these other socioeconomic objectives.

Conclusion

Globally, R&D performance has increased at a relatively high rate over the past decade and a half, averaging 6.7% annually. Worldwide R&D performance (measured as expenditures) totaled an estimated $1.918 trillion (current PPP dollars) in 2015, the latest global total available. The comparable figure for 2010 was $1.415 trillion, and $722 billion in 2000.

U.S. R&D increased to $495.1 billion in 2015 (Table 4-1; Appendix Table 4-1), which represented 26% of the global total that year. The comparable U.S. figure for 2010 was $406.6 billion and $268.0 billion in 2000. The United States remains the world's largest R&D performer. Nonetheless, investments in R&D by other countries—particularly those in Asia—continue to increase, further eroding the longstanding U.S. lead. China ($408.8 billion of R&D in 2015) has now moved well ahead of Japan ($170.0 billion) as the second largest R&D-performing nation (Table 4-5). Countries or economies of the East/Southeast and South Asian regions accounted for 25% of the global total in 2000 but rose to a striking 40% in 2015. EU countries accounted for 25% of the global total in 2000 but dropped to 20% in 2015.

In 2008, just ahead of the onset of the main economic effects of the national/international financial crisis and the Great Recession, U.S. R&D totaled $404.8 billion. The total was an estimated $495.1 billion at the end of 2015. Adjusted for inflation, the annual expansion of R&D over the 2008–15 period averaged 1.4%, compared with GDP at 1.5% over the same period (Table 4-2). Further, removing the deepest of the Great Recession years (2009 and 2010), the annual growth of R&D averaged 2.3%, compared to 2.2% for GDP. On these numbers, the period since 2008 remains an uncharacteristically slow pattern of R&D expansion -- compared with 3.6% for R&D versus 2.2% for GDP over the decade immediately prior (1998–2008).

Glossary

Definitions

European Union (EU): The EU comprises 28 member nations: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, and the United Kingdom. Unless otherwise noted, data on the EU include all 28 nations.

G20: Group of Twenty brings together finance ministers and central bank governors from Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Mexico, Russia, Saudi Arabia, South Africa, South Korea, Turkey, the United Kingdom, the United States, and the European Union.

Gross domestic product (GDP): The market value of goods and services produced within a country. It is one of the main measures in a country's national income and product accounts, which record the value and composition of national output and the distribution of the incomes generated in this production (BEA 2015).

Multinational enterprise (MNE): A parent company and its foreign affiliates. An affiliate is a company or business enterprise (incorporated or unincorporated) located in one country but owned or controlled (10% or more of voting securities or the equivalent) by a parent company in another country. A majority-owned affiliate is a company owned or controlled by more than 50% of the voting securities (or equivalent) by its parent company.

Organisation for Economic Co-operation and Development (OECD): An international organization of 35 countries, headquartered in Paris, France. The member countries are Australia, Austria, Belgium, Canada, Chile, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Latvia, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Slovakia, Slovenia, South Korea, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States. Among its many activities, the OECD compiles social, economic, and science and technology statistics for all member and selected nonmember countries.

R&D: Research and experimental development comprise creative and systematic work undertaken in order to increase the stock of knowledge—including knowledge of humankind, culture, and society—and its use to devise new applications of available knowledge.

> **Basic research:** Experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, without any particular application or use in view.
>
> **Applied research:** Original investigation undertaken in order to acquire new knowledge; directed primarily, however, toward a specific, practical aim or objective.
>
> **Experimental development:** Systematic work, drawing on knowledge gained from research and practical experience and producing additional knowledge, which is directed to producing new products or processes or to improving existing products or processes (OECD 2015).

R&D intensity: A measure of R&D expenditures relative to size, production, financial, or other characteristics for a given R&D-performing unit (e.g., country, sector, company). Examples include R&D-to-GDP ratio and R&D value-added ratio.

Key to Acronyms and Abbreviations

ANBERD: Analytical Business Enterprise R&D

ARRA: American Recovery and Reinvestment Act

BEA: Bureau of Economic Analysis

BRDIS: Business R&D and Innovation Survey

CAGR: compound average annual growth rate

DOC: Department of Commerce

DOD: Department of Defense

DOE: Department of Energy

EU: European Union

FFRDC: federally funded research and development center

FY: fiscal year

G20: Group of Twenty

GBARD: government budget appropriations for R&D

GDP: gross domestic product

GERD: gross domestic expenditures on R&D

GUF: general university fund

HE: higher education

HERD: Higher Education Research and Development Survey

HHS: Department of Health and Human Services

IRC: Internal Revenue Code

IRS: Internal Revenue Service

ISIC: International Standard Industrial Classification of All Economic Activities

MER: market exchange rate

MNE: multinational enterprise

NAICS: North American Industry Classification System

NASA: National Aeronautics and Space Administration

NCSES: National Center for Science and Engineering Statistics

nec: not elsewhere classified

NIH: National Institutes of Health

NIPA: national income and product accounts

NSF: National Science Foundation

OECD: Organisation for Economic Co-operation and Development

ONP: other nonprofit organization

OPEC: Organization of the Petroleum Exporting Countries

OWH: other Western Hemisphere

PPP: purchasing power parity

PST: professional, scientific, and technical

R&D: research and development

R&E: research and experimentation

S&E: science and engineering

UK: United Kingdom

UNESCO: United Nations Educational, Scientific and Cultural Organization

USDA: Department of Agriculture

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CHAPTER 5

Academic Research and Development

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Highlights

Spending for Academic R&D

In 2016, U.S. academic institutions spent $72 billion on research and development.

- Basic research constituted just under two-thirds of academic R&D spending; the remainder was split between applied research (28%) and development (9%).
- Although the federal government provided more than half of academic R&D funds in 2016 (54%), its share declined for the fifth year in a row.
- By contrast, universities' share of academic R&D spending has grown in recent years and reached its highest level ever in 2016 (25%).

Six agencies provided more than 90% of federal support for academic R&D.

- In declining order of funding and based on reports from universities, the major federal agencies that support academic R&D are the Department of Health and Human Services (HHS), the Department of Defense (DOD), the National Science Foundation (NSF), the Department of Energy (DOE), the National Aeronautics and Space Administration (NASA), and the Department of Agriculture.
- HHS (mainly through the National Institutes of Health) provides the majority of total federal funds for life sciences and psychology.
- NSF and DOD together provide the majority of federal funding for computer sciences, mathematical sciences, and engineering.
- HHS, NSF, and DOD together provide the majority of federal funding for social sciences.
- NSF and NASA together provide half of the federal funding for geosciences, while NSF and DOE together provide half of the federal funding for physical sciences.

Over most of the last three decades, the distribution of academic R&D expenditures shifted in favor of life sciences and away from physical sciences. However, over the last decade, engineering R&D has grown faster than R&D in life sciences.

- Life sciences received the largest share (57%) of funding in 2016, followed by engineering (16%).
- Within life sciences, biological and biomedical sciences and health sciences have grown more rapidly than agricultural sciences.
- Within engineering, bioengineering and biomedical engineering and aerospace engineering have grown faster than the other engineering fields, although from lower bases.
- The other broad fields of science—computer sciences, geosciences, mathematical sciences, physical sciences, psychology, and social sciences—together accounted for 20% of academic R&D spending in 2016.
- Just under 2% of academic R&D expenditures were not classified within a broad field of science and included a portion of the multidisciplinary or interdisciplinary R&D conducted by U.S. academic institutions.
- Non-S&E fields—such as education, business, and humanities—accounted for just under 6% of total spending.

Funding sources for academic R&D continued to differ in importance for public and private institutions in 2016.

- Public universities relied more heavily than private ones on state and local government funds (8% versus 1%) and more heavily on their own funds (27% versus 21%).
- Private universities relied more heavily on the federal government (60% versus 51%).
- Private universities relied a bit more than their public counterparts on business funding (7% versus 5%) and nonprofit funding (8% versus 6%).

Infrastructure for Academic R&D

Research space at academic institutions has continued to grow annually since the 1980s, although the pace of growth has slowed over the last decade.

- Total research space at universities and colleges increased by 1.4% from 2013 to 2015, which was the smallest growth in three decades.
- Research space for the biological and biomedical sciences accounted for 26% of all S&E research space in 2015, making it the largest of all the major fields.
- In 2015, 80% of research space was reported as being in either superior or satisfactory condition by academic institutions, 16% required renovations, and 4% needed replacement.

In 2016, universities spent just over $2.1 billion on movable capitalized research equipment, an increase of 3% from the amount spent in 2015.

- Equipment spending accounted for 3.1% of total academic S&E R&D expenditures in 2016, which was the lowest share in three decades.
- Three S&E fields accounted for 87% of equipment expenditures in 2016: life sciences (40%), engineering (29%), and physical sciences (18%).
- In 2014, the federal share of support for all academic research equipment funding fell below 50% for the first time since data collection began in 1981. The 2016 federal support share remained below 50% for the third consecutive year, reaching 45%. This share reached 63% as recently as 2011.

Doctoral Scientists and Engineers in Academia

The academic workforce with research doctorates in science, engineering, and health (hereafter referred to as *S&E*) numbered just under 400,000 in 2015.

- The vast majority of this population (about 330,000) was trained in the United States. The foreign-trained portion numbered about 68,000.
- Between 2013 and 2015, the S&E doctoral workforce grew more slowly in the academic sector (7%) than in the business sector (15%).
- In 2015, about 45% of the U.S.-trained S&E doctorate holders were employed in academia, compared with just under 50% in the mid-1990s and 55% in the early 1970s.

Full-time faculty positions for U.S.-trained S&E doctorate holders have been in steady decline for four decades, offset by a rise in other types of full- and part-time positions.

- The percentage of S&E doctorate holders employed in academia who held full-time faculty positions declined from about 90% in the early 1970s to about 70% in 2015.
- Compared with 1995, a smaller share of the doctoral academic workforce had achieved tenure in 2015. In 1995, tenured positions accounted for an estimated 53% of doctoral academic employment; this decreased to 47% in 2015. Tenure-track positions as a share of doctoral academic employment declined slightly between 1995 and 2015, while the share of positions outside of the tenure system increased.

The demographic profile of the U.S.-trained academic doctoral workforce has shifted substantially over time.

- The number of women in academia grew rapidly between 1995 and 2015, more than doubling from 52,000 to 123,000. In 2015, women constituted 37% of academically employed doctorate holders, up from 24% in 1995. Women as a share of full-time senior doctoral faculty also increased substantially.
- Among younger individuals (those degreed since 1995), women constituted 44% of the academic doctoral workforce, while among the older cohort (those degreed in 1994 or earlier), women constituted only 26%.
- In 2015, underrepresented minorities (blacks, Hispanics, and American Indians or Alaska Natives) constituted 8.9% of total academic doctoral employment and 8.6% of full-time faculty positions, up from about 2% in 1973 and from 7%–8% of these positions in 2003.
- Among women in full-time faculty positions, 10.5% were from underrepresented minority groups, a higher percentage than for their male counterparts (7.6%).
- Among those degreed since 1995, underrepresented minorities held 10.2% of full-time faculty positions, while among the cohort degreed before 1995, they held only 6.5% of full-time faculty positions.
- Just under 30% of U.S.-trained doctorate holders in academia were foreign born, contrasted with about 12% in 1973 and 19% in 1995.
- Over one-half of all U.S.-trained postdoctorates (postdocs) were born outside of the United States.
- The U.S.-trained doctoral academic workforce has aged substantially over the past two decades. In 2015, 25% of those in full-time faculty positions were between 60 and 75 years of age, compared with 11% in 1995.

Since 1993, the proportion of full-time faculty who identify research as their primary work activity has increased, and the proportion of full-time faculty who identify teaching as their primary activity has decreased.

- Just under 40% of full-time faculty identified research as their primary work activity in 2015, up from 33% in 1993.
- The share of full-time faculty who identified teaching as their primary activity declined from 53% in 1993 to 45% in 2015.
- In 2015, 35% of recently degreed full-time faculty identified research as their primary work activity.

A substantial pool of academic researchers exists outside the ranks of tenure-track faculty.

- Approximately 45,000 S&E doctorate holders were employed in academic postdoc positions in 2015, most of whom earned their doctorate overseas.

- In 2015, 35% of U.S.-trained doctorate holders less than 4 years beyond receiving the doctorate held academic postdoc positions, about the same share (36%) as employed in full-time faculty positions. Among those 4–7 years beyond receiving their doctorates, 16% held postdoc positions.
- Beyond postdocs and full-time faculty, other S&E doctorate holders engaged in academic R&D include research associates and adjunct faculty.

The share of U.S.-trained academic doctorate holders receiving federal research support declined somewhat since the early 1990s.

- In 2015, about 41% of doctorate holders received federal research support, compared with 48% during the late 1980s and very early 1990s.
- Among full-time faculty, recent doctorate recipients were less likely to receive federal research support than their more established colleagues.
- Federal research support has become less available to doctorate holders in nonfaculty positions, declining from about 60% in 1973 to about 42% in 2015.

Outputs of S&E Research: Publications

U.S. researchers accounted for just under one-fifth of the global output volume of peer-reviewed S&E articles; academic researchers contributed about three-quarters of the U.S. total. In 2016, China and the United States were the two largest global producers of peer-reviewed S&E articles.

- China and the United States produced 18.6% and 17.8%, respectively, of the world's 2.3 million total S&E publications in 2016. Over the last decade for which data are available, between 2006 and 2016, the U.S. share declined from 24.4%, while China's share grew from 12.1%.
- The period from 2006 to 2016 shows the ascendance of the share of peer-reviewed publications from Asia and India. China's compound annual growth rate of 8.43% was one of the fastest growing among the top 15 producers of S&E publications. Also among the top 15 producers, Iranian output grew the fastest, growing 15.1% annually from 2006 to 2016. Indian researcher output grew at an annual rate of 11.1%.
- Japan, the country with the sixth largest share of S&E publications in 2016, experienced a decline in global share from 7.0% to 4.2% from 2006 to 2016. Shares of Germany and the United Kingdom, the fourth and fifth largest producers, declined from 5.4% to 4.5% and from 5.6% to 4.3%, respectively.
- India is the third largest producer of S&E articles, with a 4.8% share of world S&E publication output in 2016. South Korea reached 2.8%, while Brazil reached 2.3%.
- When viewed as one region, the share for the European Union (EU) declined, from 30.7% in 2006 to 26.7% in 2016.

Biological and medical sciences dominate research output in the United States, Japan, and the EU. Engineering publications account for the greatest percentage of the publications from China.

- Among the major producers of S&E publications, the United States has the highest concentration of publications in medical sciences.
- The United States has 47.2% and the EU has 39.4% of their publications in two fields combined, biological and medical sciences. Japan has 43.1% of its publications in those fields.

- China has 28.9% of its publications in engineering and 27.3% in biological and medical sciences combined.
- Of these major producers, India has the highest concentration of publications in computer sciences and the second highest concentration in engineering.

S&E research publications are increasingly collaborative and increasingly international in authorship.

- More than 64.7% of global S&E publications had multiple authors in 2016, compared with about 60.1% of such publications in 2006.
- The percentage of worldwide publications produced with international collaboration (i.e., by authors with institutional addresses from at least two countries) rose from 16.7% to 21.7% between 2006 and 2016.
- International collaboration grew between 2006 and 2016 in all fields of science, with the highest percentage of international collaboration in astronomy.
- In the United States, 37.0% of publications were coauthored with researchers at institutions in other countries in 2016, compared with 25.2% in 2006.
- Among the major producers of S&E publications, the United Kingdom had the highest international collaboration rate in 2016, at 57.1%.

The impact of S&E publications has also become more global. U.S. S&E publications increasingly cite S&E publications from foreign authors and increasingly receive citations from foreign-authored publications.

- World citations to U.S. research publications increased from 47.0% to 55.7% between 2004 and 2014.
- The average impact of U.S. publications—a measure of citations received relative to the number of S&E articles published and the fields in which they appear—was 42% higher in 2014 than the global average for citations.
- China's citation rate rapidly increased across 2004–14, improving from fewer citations than would be expected, based on number of publications from China's researcher institutions, to just reaching the expected level of citations.
- In 2014, publications with U.S. authors were almost twice as likely to be among the world's top 1% most-cited publications than would be expected based on the volume of U.S. publications.
- By this measure, S&E publications from the Netherlands, Sweden, and Switzerland are more than twice as likely to be among the top 1% of highly cited articles.

Introduction

Chapter Overview

Financial resources for the large and decentralized U.S. R&D system exceeded $450 billion in recent years. R&D performed by academic institutions, relatively small at about 15% of total expenditures, has a vital role that belies its size in the overall system. Universities conduct just under half of the nation's basic research and, in the process, introduce undergraduates to research protocols, train graduate students and future doctorate holders, and support postdoctoral researchers in conducting advanced scientific inquiry.[1] Knowledge generated from this work is broadly shared in international peer-reviewed journals, in which U.S.-based authors feature prominently.

Chapter Organization

The chapter opens with an examination of trends in spending on academic R&D. It discusses funding sources and spending patterns by institution types and fields. Comparisons are made between public and private institutions and between very high research activity institutions and others. This section illustrates the important role of federal funding for academic R&D, showing a continuing decline in the federal share of total spending, while the share paid for by universities themselves has increased.

The second section analyzes trends in infrastructure by field for academic R&D, including research facilities and research equipment. In addition, this section comments on the role of academic research cyberinfrastructure, such as high-performance computing, networking, and storage resources.

The chapter then turns to the people conducting academic research and teaching the next generation of scientists and engineers. It traces substantial, decades-long trends in the demographics of the academic doctoral workforce, structural changes in its composition, and patterns in the distribution of federal funds that support this workforce's research. The chapter's focus broadens with an examination of research articles (the bulk involving results of academic R&D) in global peer-reviewed journals. This examination of the U.S. role in the broad realm of international R&D focuses on the volume, patterns, and fields of publication; the growth of coauthorship; and domestic and international collaboration. Citation patterns allow inferences about the relative impact of academic R&D output.

The fields of science and engineering presented in this chapter reflect several small differences between each section's data sources. For example, the section Expenditures and Funding for Academic R&D presents data by S&E field as defined in the survey of Higher Education Research and Development (HERD), while the section Doctoral Scientists and Engineers in Academia presents data by S&E field as defined in the Survey of Doctorate Recipients (SDR). The data sources generally group fields consistently, with a few exceptions.[2]

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[1] Higher education institutions are primary performers of U.S. basic research, accounting for 49% of the $83.5 billion of basic research performance in 2015. The business sector performed about 26%, the federal government (agency intramural laboratories and federally funded research and development centers [FFRDCs]) performed 12%, and other nonprofit organizations performed 13%. See Chapter 4 for further discussion of national patterns of R&D.

[2] While the data sources generally group fields consistently, there are a few differences. In particular, SDR groups earth, atmospheric, and ocean sciences under physical sciences, whereas the other data sources used in this chapter group these sciences under geosciences. In the bibliometric data, chemistry and physics are separate broad fields; in the chapter's other data sources, however, these fields are included within the broad field of physical sciences.

Expenditures and Funding for Academic R&D

Academic R&D is a key component of the overall U.S. R&D enterprise.[1] Academic institutions conduct just under half of the nation's basic research and, importantly, train young researchers in the process. (For an overview of the sources of data used, see sidebar Data on the Financial and Infrastructure Resources for Academic R&D.)

SIDEBAR

Data on the Financial and Infrastructure Resources for Academic R&D

Financial data on academic R&D are drawn from the National Science Foundation's Survey of Research and Development Expenditures at Universities and Colleges (1972–2009) and its successor, the Higher Education Research and Development Survey (HERD; 2010 onward). Trend analysis is possible because both surveys capture comparable information on R&D expenditures by sources of funds and by field. HERD offers a more comprehensive treatment of R&D (including non-S&E fields), an expanded group of surveyed institutions, and greater detail about the sources of funding for R&D expenditures by field (Britt 2010). The latest survey is available at https://www.nsf.gov/statistics/srvyherd/.

HERD data are in current-year dollars and are reported on an academic-year basis. For example, FY 2016 covers July 2015–June 2016 for most institutions and is referred to in this chapter as 2016. HERD data are generally presented in current dollars, although comparisons over more than 1 year are made in inflation-adjusted constant 2009 dollars using gross domestic product implicit price deflators.

The data on research facility infrastructure come from the Survey of Science and Engineering Research Facilities. This survey includes all universities and colleges in HERD with $1 million or more in S&E R&D expenditures and is completed by university and college administrators under the direction of the institutional presidents. The latest survey is available at https://nsf.gov/statistics/srvyfacilities/.

Data on federal obligations for academic R&D are reported in Chapter 4; that chapter also provides data on the academic sector's share of the nation's overall R&D.

National Academic R&D Expenditures in All Fields

R&D expenditures by U.S. colleges and universities totaled $71.8 billion in 2016.[2] ,[3] The vast majority (94%) of this spending was in S&E fields (▦ Table 5-1). The chapter will also present Higher Education Research and Development Survey (HERD) data that are not distributed by field. Such data include institutions' estimates of spending for basic research, applied research, and development (▦ Table 5-2; Appendix Table 5-1); data on R&D funds that universities and colleges pass through to other institutions (or receive from others); detail on institutionally financed R&D; and the types of costs universities incur as they conduct R&D.

TABLE 5-1

R&D expenditures at universities and colleges, by field: FY 2016

(Millions of current dollars)

Field	Total expenditures	Federal expenditures
All R&D fields	71,833	38,794
Computer and information sciences	2,078	1,443
Geosciences, atmospheric sciences, and ocean sciences	3,088	1,993
Life sciences	40,888	21,798
Mathematics and statistics	682	444
Physical sciences	4,894	3,287
Psychology	1,219	761
Social sciences	2,367	899
Sciences nec	1,077	465
Engineering	11,382	6,583
Non-S&E	4,161	1,120

nec = not elsewhere classified.

Note(s)

Detail may not add to total because of rounding.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Higher Education Research and Development Survey (HERD), FY 2016.

Science and Engineering Indicators 2018

Academic R&D spending is primarily for basic research—in 2016, 63% was spent on basic research, 28% was spent on applied research, and 9% was spent on development (▦Table 5-2),[4] percentages largely unchanged from 2015. The estimated percentage of spending on basic research from 2010 to 2016 (around 65%) is less than institutions had reported throughout the late 1990s and the 2000–09 decade (around 75%) (Appendix Table 5-1). Improvements to the survey question in 2010 likely affected how universities reported these shares.[5]

TABLE 5-2

Higher education R&D expenditures, by source, character of work, and institution type: FYs 2012–16

(Thousands of dollars)

Fiscal year	Institution type	All sources				Federal sources			
		Total	Basic research	Applied research	Experimental development	Total	Basic research	Applied research	Experimental development
2012	All institutions	65,729,007	42,401,697	17,295,653	6,031,657	40,142,223	26,469,347	10,577,754	3,095,122
	Public	44,162,595	28,763,003	11,666,386	3,733,206	25,109,740	16,571,834	6,654,107	1,883,799
	Private	21,566,412	13,638,694	5,629,267	2,298,451	15,032,483	9,897,513	3,923,647	1,211,323
2013	All institutions	67,013,138	43,305,409	17,390,865	6,316,864	39,445,931	26,071,617	10,327,219	3,047,095
	Public	44,849,697	28,878,632	11,910,906	4,060,159	24,688,555	16,200,772	6,615,036	1,872,747
	Private	22,163,441	14,426,777	5,479,959	2,256,705	14,757,376	9,870,845	3,712,183	1,174,348
2014	All institutions	67,196,537	42,989,478	17,745,860	6,461,199	37,960,175	24,905,121	10,015,778	3,039,276
	Public	44,675,392	28,553,622	11,848,740	4,273,030	23,496,472	15,330,179	6,199,866	1,966,427
	Private	22,521,145	14,435,856	5,897,120	2,188,169	14,463,703	9,574,942	3,815,912	1,072,849
2015	All institutions	68,566,890	43,865,982	18,022,569	6,678,339	37,848,552	24,945,232	9,969,994	2,933,326
	Public	45,428,567	28,984,600	12,036,229	4,407,738	23,389,238	15,368,215	6,183,940	1,837,083
	Private	23,138,323	14,881,382	5,986,340	2,270,601	14,459,314	9,577,017	3,786,054	1,096,243
2016	All institutions	71,833,308	45,101,655	19,986,766	6,744,887	38,793,542	24,944,577	10,893,286	2,955,679
	Public	47,147,814	29,778,373	12,961,231	4,408,210	23,947,624	15,394,204	6,709,633	1,843,787
	Private	24,685,494	15,323,282	7,025,535	2,336,677	14,845,918	9,550,373	4,183,653	1,111,892

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Higher Education Research and Development Survey (HERD).

Science and Engineering Indicators 2018

National Academic R&D Spending

Academic R&D expenditures are made up of a variety of direct and indirect cost components. The largest cost component is the salaries of those who conduct the R&D. In 2016, salaries, wages, and fringe benefits constituted 44% of total spending ($31.5 billion). The remaining 56% was divided between all other direct costs (33% of total spending) and indirect costs (23% of total spending). Other direct costs include, among other things, funds passed through to subrecipients for collaborative projects and purchases of software and equipment. Indirect costs include both recovered and unrecovered costs (together totaling $16.5 billion in 2016) (▦Table 5-3).[6]

TABLE 5-3

Higher education R&D expenditures, by Carnegie classification, institution type, and type of cost: FY 2016

(Thousands of dollars)

Carnegie classification and institution type	All R&D expenditures	Direct costs								Indirect costs		
		Total	Salaries, wages, and fringe benefits	Software purchases			Capitalized equipment	Passed through to subrecipients	Other direct costs	Total	Recovered	Unrecovered
				Total	Noncapitalized software	Capitalized software						
All institutions	71,833,308	55,299,302	31,476,669	113,777	95,247	18,530	2,171,192	5,733,598	15,804,066	16,534,006	11,460,964	5,073,042
Research universities — very high research activity	51,249,576	38,866,432	22,077,133	62,795	56,434	6,361	1,473,962	4,265,477	10,987,065	12,383,144	8,742,566	3,640,578
All other universities and colleges	20,583,732	16,432,870	9,399,536	50,982	38,813	12,169	697,230	1,468,121	4,817,001	4,150,862	2,718,398	1,432,464
Public	47,147,814	36,991,418	21,773,123	89,480	74,178	15,302	1,578,451	3,555,996	9,994,368	10,156,396	6,622,726	3,533,670
Private	24,685,494	18,307,884	9,703,546	24,297	21,069	3,228	592,741	2,177,602	5,809,698	6,377,610	4,838,238	1,539,372

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Higher Education Research and Development Survey (HERD), FY 2016.

Science and Engineering Indicators 2018

Sources of Support for Academic R&D

Academic R&D relies on funding support from a variety of sources, including the federal government, universities' and colleges' own institutional funds, state and local government, businesses, and other organizations (Appendix Table 5-2). The federal government has consistently provided the majority of funding for academic R&D, generally around 60%, although the share has been less in recent years.[7] Institutional funds contribute a sizeable share of this funding (25% in 2016), while state and local governments, businesses, and nonprofit organizations (such as philanthropic foundations) each provide less than 10% of R&D funds.[8] Funding from all other sources results in about 3% of total R&D spending.

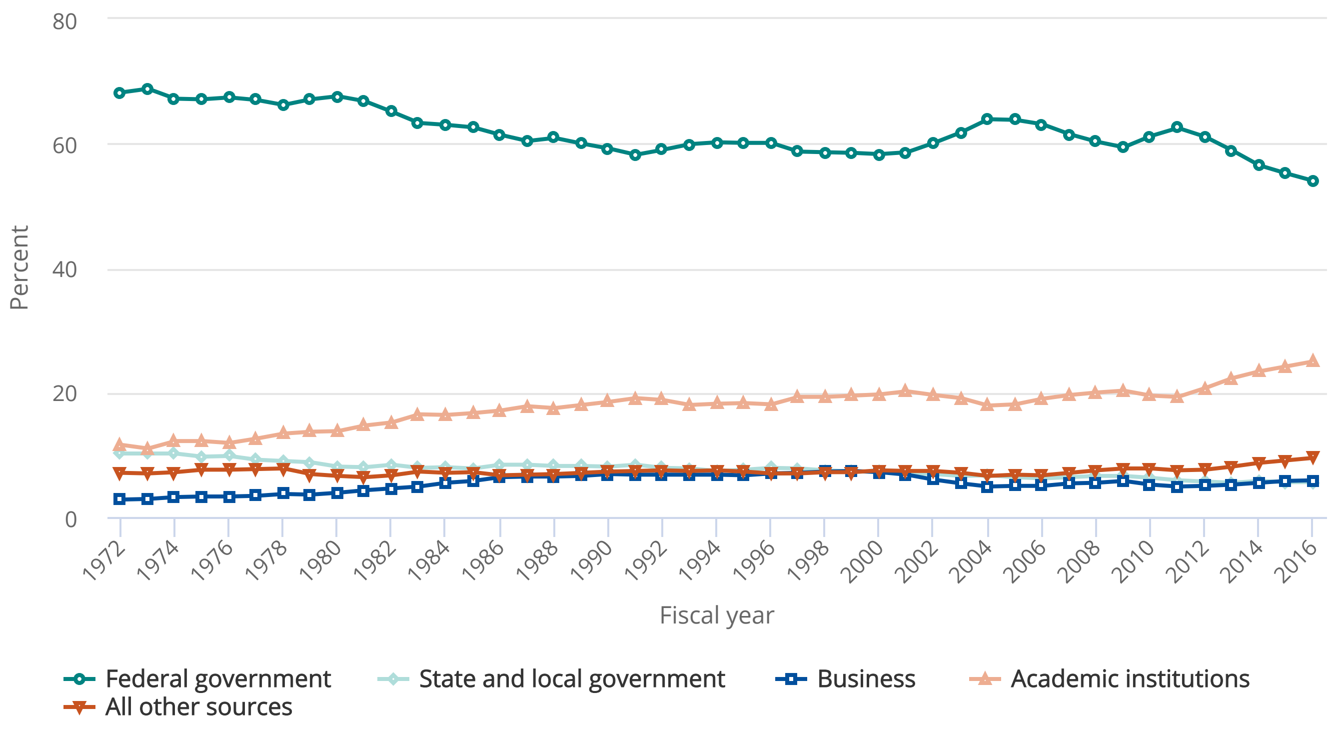
Federal Support

The federal government allocates R&D funding to academia primarily through competitive review processes, and overall support reflects the combined result of many discrete funding decisions made by the R&D-supporting federal agencies. Varying agency missions, priorities, and objectives affect the level of funds that universities and colleges receive and how those funds are spent. The American Recovery and Reinvestment Act of 2009 (ARRA) was an important source of federal expenditures for academic R&D during the economic downturn and recovery from 2010 through 2012 and continued to contribute to such spending, although in smaller amounts, in 2013 and 2014. By 2015, all ARRA funds had been spent.[9]

Excluding ARRA funds, the proportion of R&D paid for with federal funds has declined gradually since 2004 (from 64% to 54%). This decrease has contributed to a decline over this period in success rates for research grant applications at some federal funding agencies discussed in this chapter's section on doctoral scientists and engineers in academia. Taking a longer perspective, the proportion of academic R&D paid for with federal funds, at 69%, was highest in 1973 (Figure 5-1). This proportion then declined fairly steadily throughout the remainder of the 1970s and the 1980s. During the 1990s, the federal share, with some fluctuations, remained at or just under 60%. However, during the first half of the 2000–09 decade, the federal proportion of academic R&D spending gradually increased to 64%, reflecting rapid increases in the budget of the National Institutes of Health (NIH), a major academic R&D funding agency. The federal proportion fell during the latter part of the 2000–09 decade but rose in 2010 and 2011 with the infusion of ARRA funds. It has been on a steady decline starting in 2012. In 2016, the federal government was the source for $38.8 billion (54%) of the $72 billion total in R&D spending, an increase of only $400 million from 2015 after adjusting for inflation (Figure 5-2).

FIGURE 5-1

Academic R&D expenditures, by source of funding: FYs 1972–2016



Note(s)

Totals for FYs 1972–2009 represent R&D expenditures in S&E fields only. Beginning in FY 2010, totals include R&D expenditures in S&E fields and non-S&E fields. Academic institutions' funds exclude research funds spent from multipurpose accounts. Percentages may not add to 100% becaue of rounding.

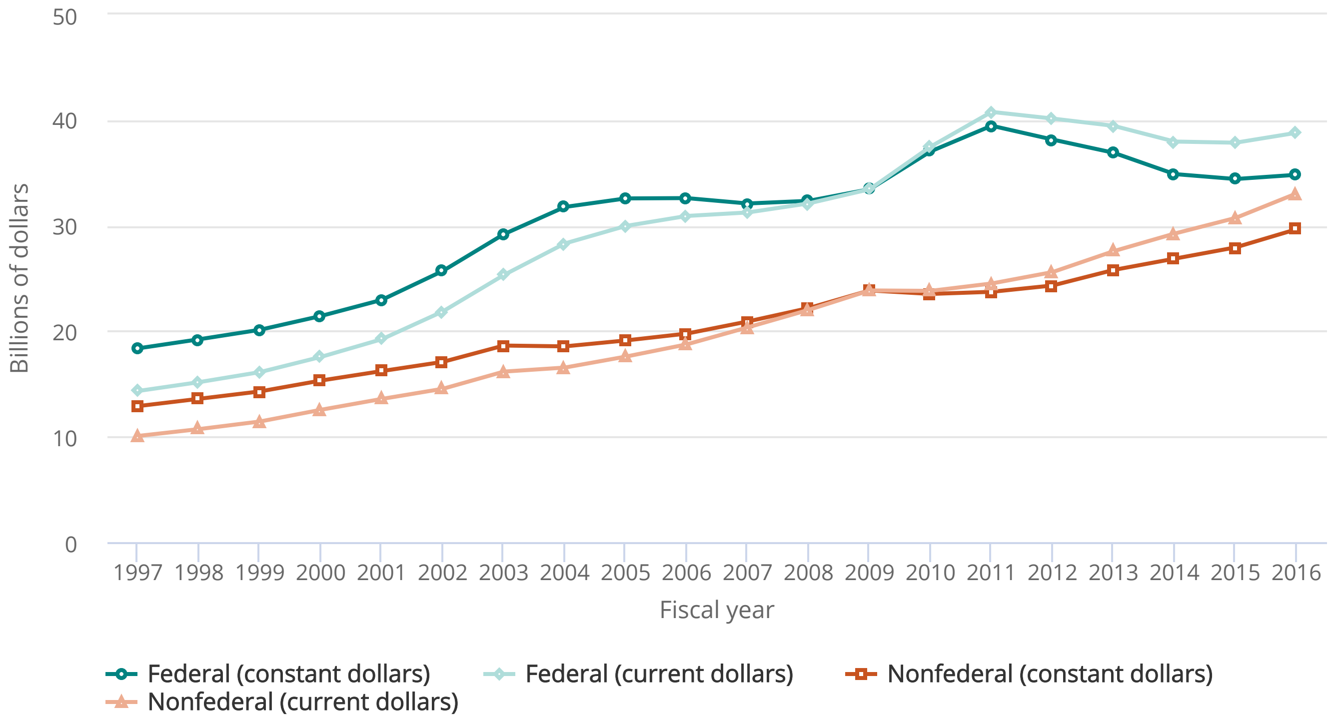
Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Higher Education Research and Development Survey (HERD).

Science and Engineering Indicators 2018

FIGURE 5-2

Federal and nonfederal funding of academic R&D expenditures: FYs 1997–2016



Note(s)

Gross domestic product deflators come from the U.S. Bureau of Economic Analysis and are available at https://www.bea.gov/national/, accessed 12 July 2017. See Appendix Table 4-1. Totals for FYs 1997–2002 represent R&D expenditures in S&E fields only. Beginning in FY 2003, totals include R&D expenditures in S&E fields and non-S&E fields. However, from FY 2003 through FY 2009, some institution totals may be lower-bound estimates because the National Science Foundation did not attempt to estimate for nonresponse on non-S&E R&D expenditures before FY 2010.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Higher Education Research and Development Survey (HERD). See Appendix Table 5-1.

Science and Engineering Indicators 2018

Top Federal Agency Supporters

Six agencies are responsible for the vast majority of annual federal expenditures for academic R&D: the Department of Health and Human Services (HHS), particularly NIH; the Department of Defense (DOD); the National Science Foundation (NSF); the Department of Energy (DOE); the National Aeronautics and Space Administration (NASA); and the Department of Agriculture (USDA). In 2016, these six agencies were the source of more than 90% of the estimated $38.8 billion federal expenditures for academic R&D (Appendix Table 5-3; Chapter 4 provides data on these agencies' obligations for academic R&D).[10]

Among these six agencies, HHS is by far the largest funder, the source of $21 billion (53%) of total federal expenditures in 2016. DOD was the next largest funder, providing $5.3 billion (just under 14%); it was followed closely by NSF, which provided $5.1 billion (just over 13%) of federal funding for academic R&D. DOE, NASA, and USDA provided smaller shares of between 3% and 5%, and all other agencies together provided 8%. For at least the last decade, the relative ranking of the top six funding agencies in terms of the amount of R&D funding has remained quite stable, with DOD experiencing the greatest gains in share (from 9% in 2007 to 14% in 2016) (Table 5-4).

TABLE 5-4

Top six federal agencies' shares of federally funded academic R&D expenditures: FYs 2007–16

(Percent)

Agency	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Department of Health and Human Services	54.7	54.5	54.0	56.3	56.4	54.6	53.8	53.5	52.8	53.3
Department of Defense	8.9	9.5	10.1	12.0	11.8	12.2	12.7	13.0	13.4	13.7
National Science Foundation	11.4	11.8	11.8	12.6	12.6	13.1	13.7	13.5	13.5	13.2
Department of Energy	3.6	3.5	3.7	4.1	4.6	4.9	4.8	4.8	4.5	4.6
National Aeronautics and Space Administration	3.4	3.3	3.3	3.9	3.5	3.3	3.4	3.5	3.7	3.8
Department of Agriculture	2.9	2.8	2.7	2.6	2.5	2.7	2.8	2.8	3.0	3.1

Note(s)

The Department of Health and Human Services includes primarily the National Institutes of Health.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2017) of the Higher Education Research and Development Survey (HERD).

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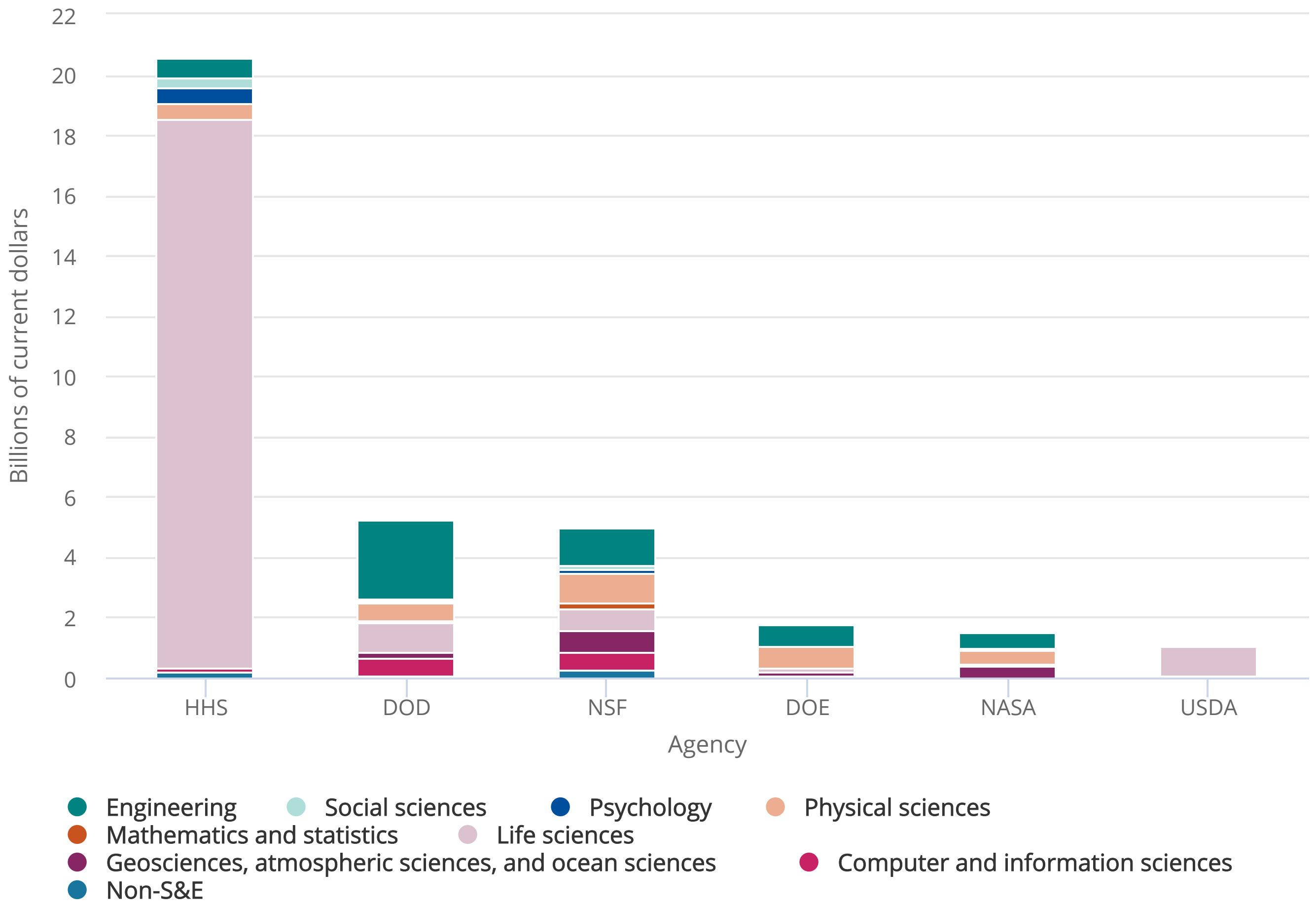
The federal government's role in funding R&D in the various fields of S&E hinges on each agency's mission focus (Figure 5-3). Federal funding has played a larger role in overall support for some fields than for others (Appendix Table 5-4). The federal government is the dominant funder in fields such as atmospheric sciences (82% in 2016), physics (72%), computer sciences (69%), and aerospace engineering (71%). It plays a smaller role in other fields, such as economics (28%), agricultural sciences (30%), and political sciences (27%).

FIGURE 5-3

Federally financed academic R&D expenditures, by agency and S&E field: FY 2016



DOD = Department of Defense; DOE = Department of Energy; HHS = Department of Health and Human Services; NASA = National Aeronautics and Space Administration; NSF = National Science Foundation; USDA = Department of Agriculture.

Source(s)

SOURCE(S): National Science Foundation, National Center for Science and Engineering Statistics, Higher Education Research and Development Survey (HERD), FY 2016. See Appendix Table 5-3.

Science and Engineering Indicators 2018

Although fields vary in their dependence on particular agencies, most receive the majority of their funding from only one or two agencies. HHS—primarily through NIH—supports the vast majority of federal funding in life sciences (83%) and the majority (66%) of federal funding in psychology. NSF and DOD together play key roles in computer sciences (83%), mathematical sciences (79%), and engineering (59%). Funding sources for R&D in geosciences and social sciences are more diversified, with NSF and NASA providing large proportions of geosciences funding and HHS providing the largest proportion of social sciences funding (Table 5-5). In 2016, as in previous years, NSF was the lead federal funding agency for academic research in physical sciences, mathematical sciences, and geosciences. In 2016, DOD was the lead funding agency in engineering and computer sciences.

Federal support for academic R&D historically has been concentrated in the nation's most research-intensive higher education institutions. Recognizing that human talent is widespread, federal government agencies have long supported a program to develop academic research capability in states that are less competitive in obtaining federal research grants. See sidebar 💬 Established Program to Stimulate Competitive Research for an overview of the program and recent statistics on its activities.

TABLE 5-5

Federal funding of academic S&E R&D, by agency and field: FY 2016

(Percent)

Field	All federal R&D expenditures	DOD	DOE	HHS	NASA	NSF	USDA	Other[a]
All R&D fields	38,793,542	13.7	4.6	53.3	3.8	13.2	3.1	8.3
Computer sciences	1,442,771	41.9	4.0	5.6	1.1	40.9	0.2	6.3
Geosciences	1,992,990	9.5	5.3	3.2	17.7	35.4	1.6	27.3
Life sciences	21,798,334	4.4	0.7	83.2	0.4	3.3	4.5	3.4
Mathematical sciences	444,419	27.1	2.6	10.5	0.7	51.7	1.1	6.3
Physical sciences	3,286,816	16.0	21.3	15.8	14.3	29.8	0.2	2.6
Psychology	761,433	9.2	0.1	65.7	2.9	9.3	0.9	12.0
Social sciences	898,576	8.6	1.2	36.0	0.9	16.2	5.6	31.7
Sciences nec	465,015	23.0	3.7	23.5	1.4	28.0	2.6	17.8
Engineering	6,583,476	39.6	10.6	10.0	7.8	19.3	1.0	11.7
Non-S&E	1,119,712	5.1	0.6	19.6	0.8	23.5	3.7	46.7

nec = not elsewhere classified.

DOD = Department of Defense; DOE = Department of Energy; HHS = Department of Health and Human Services; NASA = National Aeronautics and Space Administration; NSF = National Science Foundation; USDA = Department of Agriculture.

[a] Includes all other agencies reported.

Note(s)

The Department of Health and Human Services includes primarily the National Institutes of Health. Percentages may not add to 100% because of rounding.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2017) of the Higher Education Research and Development Survey (HERD).

Science and Engineering Indicators 2018

SIDEBAR

Established Program to Stimulate Competitive Research

The Established Program to Stimulate Competitive Research (EPSCoR)* is a long-standing multiagency federal program that aims to develop and raise states' capacity to compete for federal R&D grants and thus contribute to the national R&D capacity. It is based on the premise that universities and their S&E faculty and students are resources that can influence a state's development in the 21st century just as agricultural, industrial, and natural resources did in the 20th century.

EPSCoR is rooted in the history of the National Science Foundation (NSF) and of federal support for R&D. In 1978, Congress, concerned about a geographic concentration of federal R&D funds, authorized NSF to initiate EPSCoR, which was targeted at states that received lesser amounts of federal R&D funds but demonstrated a commitment to developing sustainable, competitive research capabilities anchored in academic institutions across the jurisdictions. The ultimate aim was to move EPSCoR researchers and institutions into the mainstream of federal and private-sector R&D support.

The experience of the NSF EPSCoR program during the 1980s prompted Congress to authorize the creation of EPSCoR and EPSCoR-like programs in six other federal agencies: the Departments of Energy, Defense (DOD), and Agriculture; the National Aeronautics and Space Administration; the National Institutes of Health; and the Environmental Protection Agency (EPA). Two of these agencies, EPA and DOD, discontinued issuing EPSCoR program solicitations in FYs 2006 and 2010, respectively.

In FY 2016, the five remaining agencies spent a total of $562 million on EPSCoR and EPSCoR-like programs, up from $288.9 million (all agencies) in 2002 (▦ Table 5-A).

TABLE 5-A

EPSCoR and EPSCoR-like program budgets, by agency: FYs 2002–16

(Millions of dollars)

Agency	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
All agencies	288.9	358.0	353.3	367.4	367.1	363.1	418.9	437.2	460.1	436.0	483.4	461.0	488.6	508.8	562.0
DOD	15.7	15.7	8.4	11.4	11.5	9.5	17.0	14.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DOE	7.7	11.7	7.7	7.6	7.3	7.3	14.7	16.8	21.6	8.5	8.5	8.4	10.0	10.0	14.8
EPA	2.5	2.5	2.5	2.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NASA	10.0	10.0	10.0	12.0	12.5	12.8	15.5	20.0	25.0	25.0	18.0	18.0	18.0	18.0	18.0
NIH[a]	160.0	210.0	214.0	222.0	220.0	218.0	223.6	224.3	228.8	226.5	276.5	261.6	273.3	273.3	320.8
NSF	79.3	88.8	93.7	93.4	97.8	101.5	120.0	133.0	147.1	146.8	150.9	147.6	158.2	165.5	160.0
USDA	13.7	19.3	17.0	18.6	18.0	14.0	28.1	29.0	37.6	29.2	29.5	25.4	29.1	42.0	48.4

[a] NIH has an EPSCoR-like program known as the Institutional Development Award program.

DOD = Department of Defense; DOE = Department of Energy; EPA = Environmental Protection Agency; EPSCoR = Established Program to Stimulate Competitive Research; NASA = National Aeronautics and Space Administration; NIH = National Institutes of Health; NSF = National Science Foundation; USDA = Department of Agriculture.

Note(s)

EPA and DOD discontinued issuing separate EPSCoR program solicitations in FYs 2006 and 2010, respectively. USDA's reported budget in FY 2012 included $6.8 million in unobligated funds. NASA made minor revisions to prior-year data in 2014.

Source(s)

Data are provided by agency EPSCoR representatives and are collected by the National Science Foundation Office of Integrative Activities, Office of EPSCoR, January 2017.

Science and Engineering Indicators 2018

*Prior to 2017, the program was known as the Experimental Program to Stimulate Competitive Research.

Institutional Support for Academic R&D

Notwithstanding the continuing dominant federal role in academic R&D funding, nonfederal funding sources have grown steadily over the past 20 years (Figure 5-2). Adjusted for inflation, nonfederal funding for academic R&D grew at a 4.5% average annual rate between 1997 and 2016, compared with a 3.6% average annual growth rate for federal funding for academic R&D. Growth has been particularly strong in institutions' own funds, the largest source of nonfederal funding. In 2016, institutional funds reached $18 billion (25% of the total) (Appendix Table 5-2). This share grew rapidly from only 11% in 1973 to around 18% by 1990 (Figure 5-1). With some fluctuation, universities' and colleges' share of R&D spending increased more slowly during the decades of 1990–99 and 2000–09. With the infusion of federal ARRA funds, the institutional share dipped slightly in 2010 and 2011 but has since climbed to 25%, its highest-ever share (Figure 5-1; Appendix Table 5-2).

In addition to internal funding from general revenues, institutionally financed R&D includes unrecovered indirect costs and committed cost sharing (discussed in greater detail as follows, where differences between public and private research institutions are highlighted).[11]

Institutionally financed research includes organized research projects fully supported with internal funding and all other separately accounted-for institutional funds for research. This category does not include funds spent on research that are not separately accounted for, such as estimates of faculty time budgeted for instruction that is spent on research. Funds for institutionally financed R&D may also derive from general-purpose state or local government appropriations; general-purpose awards from industry, foundations, or other outside sources; endowment income; and gifts. Universities may also use income from patents and licenses or revenue from patient care to support R&D.[12] (See Chapter 8 section USPTO Patenting Activity for a discussion of patent and licensing income.)

Other Sources of Funding

State and local government funds

State and local governments provided $4 billion (5.6%) of academic R&D funding in 2016. Public institutions received over 90% of the total (Figure 5-1; Appendix Table 5-2). The state and local government funding share has declined from a peak of 10% in the early 1970s to below 6% in recent years. However, actual amounts may be understated, particularly for public institutions, because they reflect only funds specifically targeted for R&D, while general-purpose funds may be designated by the recipient institutions for R&D or indirect cost recovery and may thus show up as institutional research support. (See State Indicators for some indicators of academic R&D by state, and see Chapter 2 section Trends in Higher Education Expenditures and Revenues for a discussion of trends in higher education spending and revenues.)

Nonprofit funds

Nonprofit organizations provided $4.6 billion (6.4%) of academic R&D funding in 2016 (Appendix Table 5-4). About two-thirds of nonprofit funding (66%) is directed toward R&D in life sciences, with health sciences being the largest recipient field within life sciences.

Business funds

Businesses provided $4.2 billion (5.9%) of academic R&D funding in 2016, slightly less than the amount provided by nonprofit organizations and slightly more than that provided by state and local governments (Figure 5-1; Appendix Table 5-4). Business funding is largely directed toward R&D in the life sciences (61%) and engineering (25%).

Other funds

In 2016, all other sources of support, such as foreign-government funding or gifts designated for research, accounted for $2.2 billion (3%) of academic R&D funding (Appendix Table 5-4).

Academic R&D Expenditures, by Field

The life sciences have long accounted for the bulk of research spending: $41 billion in 2016, 57% of the total.[13] The other S&E fields, in declining order of expenditures, are engineering (16%), physical sciences (7%), geosciences (4%), social sciences (3%), computer sciences (3%), psychology (2%), and mathematical sciences (1%) (Appendix Table 5-5). Together, the non-S&E fields constitute 6% of total spending. In addition, just under 2% of academic R&D spending is allocated toward sciences that include multidisciplinary or interdisciplinary work that could not be classified within a broad field. This estimate is not comprehensive of all multidisciplinary or interdisciplinary R&D.[14] HERD asks respondents to categorize their spending within the various S&E fields to the maximum extent possible. When R&D spans more than one field, the survey asks respondents to estimate how much is in each field.

Over the past decade, engineering grew faster than the other S&E fields, at an average annual rate of more than 3% after adjusting for inflation. Computer sciences, life sciences, social sciences, and psychology each grew by roughly 2%–3% annually. The mathematical, physical, and geosciences grew more slowly, at around 1% or less annually. All fields of S&E saw slower average annual growth in recent years (from 2006 to 2015) than earlier (from 1996 to 2005) (▦Table 5-6).

TABLE 5-6

Growth of academic R&D expenditures, by field: FYs 1997–2016

(Percent)

Field	Average annual growth rate	
	1997–2006	2007–16
Computer sciences	6.1	2.8
Geosciences	3.8	0.1
Life sciences	6.4	2.1
Mathematical sciences	4.7	0.6
Physical sciences	3.2	1.2
Psychology	7.0	2.3
Social sciences	2.6	1.6
Engineering	4.8	3.2
Non-S&E	NA	6.5

NA = not available; data for non-S&E fields were not collected before FY 2003.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2017) of the Higher Education Research and Development Survey (HERD).

Science and Engineering Indicators 2018

The largest field for academic R&D, life sciences, at $41 billion, accounted for 57% of total academic spending and a slightly smaller share (56%) of federally supported academic R&D in 2016 (Appendix Table 5-4). Within life sciences, health sciences accounted for more than one-half of this field's spending (and 31% of total academic R&D), while biological and biomedical sciences constituted just under one-third of spending in the life sciences (and 18% of total academic R&D). The remainder was spread between agricultural sciences (just under 5% of total academic R&D), natural resources and conservation, and other life sciences—life sciences R&D that could not be classified into one of the subfields. Academic R&D expenditures in health sciences almost doubled from 1995 to 2004 and then grew more slowly from 2005 to 2016. The sizeable increase from 1995 to 2004 resulted, in large part, from a near doubling of NIH's budget from 1998 to 2003.

In 2016, universities spent $11.4 billion on academic R&D in engineering, the second largest field for academic R&D after the life sciences (Appendix Table 5-4). Engineering R&D—constituting 16% of total academic R&D spending and a slightly higher share (17%) of federal spending—has generally seen robust growth over the past decade. Bioengineering and biomedical engineering ($1.1 billion in 2016) and aerospace engineering ($883 million) each grew steadily over the past decade. Although these engineering fields are smaller in size than electrical ($2.5 billion), mechanical ($1.4 billion), and civil engineering ($1.3 billion), they grew faster over the past decade. Bioengineering and biomedical engineering grew by more than 75%, and aerospace engineering grew by just under 65% from 2006 to 2016 after adjusting for inflation. Chemical engineering ($885 million) grew by just under 30%, and metallurgical engineering ($772 million) increased by only 7% after adjusting for inflation (Appendix Table 5-5).

The remaining six broad fields of S&E, as well as multidisciplinary or interdisciplinary science that has not otherwise been apportioned among fields, together accounted for about 21% of total spending in 2016. Spending in physical sciences totaled $4.9 billion. These sciences—consisting of physics, chemistry, astronomy, and materials science—constituted 7% of total spending and a slightly higher share (8%) of federal spending in 2016 (Appendix Table 5-4). In 1995, by contrast, spending in physical sciences constituted more than 10% of total academic R&D spending that year (and more than 12% of federal spending).

At $3.1 billion in 2016, spending on academic R&D in geosciences was distributed among atmospheric, geological, and ocean sciences. In 2016, geosciences constituted about 4% of academic R&D and a slightly higher share (5%) of federal spending (Appendix Table 5-4). Among the geosciences, only atmospheric science grew from 2007 to 2016 after adjusting for inflation (23%). Inflation-adjusted spending decreased in geological and ocean sciences.

Universities spent $2.4 billion on R&D in social sciences in 2016. This spending constituted 3% of total spending and a lesser share (2%) of federal spending. Spending was fairly evenly distributed among economics, political science, and sociology, each receiving roughly 15%–20% of total social sciences funding, while the smaller field of anthropology received a smaller share (4%). The remainder (42%) was spent on archaeology, criminology, geography, linguistics, urban studies, and other disciplines (Appendix Table 5-4).

With academic R&D spending levels of $2 billion or less each in 2016, computer sciences, psychology, and mathematical sciences are the smallest broad S&E fields. Universities spent $2 billion on R&D in computer sciences, just over $1 billion in psychology, and just under $700 million in mathematical sciences.

Universities spent $4.2 billion in non-S&E fields in 2016. This spending constituted just under 6% of total spending and a much smaller share (3%) of federal spending. Spending was mainly allocated among education R&D (at $1.4 billion), business management ($650 million), and humanities ($435 million). The remaining non-S&E fields, including communications, law, and social work, each spent less than $210 million on R&D in 2016 (Appendix Table 5-4 and Appendix Table 5-5).

Academic R&D, by Public and Private Institutions

For their research support, private universities rely more than their public counterparts on the federal government (60% versus 51% of their total R&D) (Figure 5-4). Conversely, public institutions derive more of their R&D funds from state government sources than private ones (8% versus 1% of their total R&D).[15]

Institutional funds, as noted earlier, play a prominent role in academic R&D spending, particularly by public universities. In 2016, public universities paid for about 27% of their R&D from their own institutional funds, while private universities paid for a smaller share (21%) (Table 5-7). Public and private institutions reported similar proportions of unrecovered indirect costs in their institutional total (28% versus 29%) (Table 5-8).[16]

In addition, private universities rely somewhat more than their public counterparts on R&D funding from businesses (6.7% versus 5.4%) and nonprofit organizations (8.1% versus 5.6%) (Figure 5-4).

TABLE 5-7

Total and institutionally funded R&D expenditures at universities and colleges, by fiscal year, institution type, and Carnegie classification: FYs 2012–16

(Thousands of dollars)

Fiscal year, institution type, and Carnegie classification	All R&D expenditures	
	Total	Institutional funds[a]
2012	65,729,007	13,587,398
Public	44,162,595	10,409,872
Research universities — very high research activity	29,343,091	7,017,320
Private	21,566,412	3,177,526
Research universities — very high research activity	17,033,727	2,261,034
2013	67,013,138	14,936,380
Public	44,849,697	11,144,662
Research universities — very high research activity	30,094,389	7,466,906
Private	22,163,441	3,791,718
Research universities — very high research activity	17,584,997	2,767,767
2014	67,196,537	15,735,059
Public	44,675,392	11,610,472
Research universities — very high research activity	30,017,465	7,863,789
Private	22,521,145	4,124,587
Research universities — very high research activity	17,860,100	3,001,686
2015	68,566,890	16,608,089
Public	45,428,226	12,135,590
Research universities — very high research activity	30,866,665	8,307,825
Private	23,138,664	4,472,499
Research universities — very high research activity	18,320,160	3,245,663
2016	71,833,308	17,974,962
Public	47,147,814	12,727,952
Research universities — very high research activity	31,841,684	8,480,727

Fiscal year, institution type, and Carnegie classification	All R&D expenditures	
	Total	Institutional funds[a]
Private	24,685,494	5,247,010
Research universities — very high research activity	19,407,892	3,858,251

[a] Excludes research funds spent from multipurpose accounts.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Higher Education Research and Development Survey (HERD).

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TABLE 5-8

Higher education R&D expenditures at all universities and colleges financed by institutional funds, by source, fiscal year, institution type, and Carnegie classification: FYs 2012–16

(Thousands of dollars)

Fiscal year, institution type, and Carnegie classification	All R&D expenditures	Institutional funds[a]			
		Total	Institutionally financed research	Cost sharing	Unrecovered indirect costs
2012	65,729,007	13,587,398	7,691,330	1,286,539	4,609,529
Public	44,162,595	10,409,872	6,295,784	845,633	3,268,455
Research universities — very high research activity	29,343,091	7,017,320	4,223,087	562,387	2,231,846
Private	21,566,412	3,177,526	1,395,546	440,906	1,341,074
Research universities — very high research activity	17,033,727	2,261,034	751,213	375,547	1,134,274
2013	67,013,138	14,936,380	8,874,662	1,358,220	4,703,498
Public	44,849,697	11,144,662	6,960,872	879,669	3,304,121
Research universities — very high research activity	30,094,389	7,466,906	4,660,195	576,464	2,230,247
Private	22,163,441	3,791,718	1,913,790	478,551	1,399,377
Research universities — very high research activity	17,584,997	2,767,767	1,180,848	406,595	1,180,324
2014	67,196,537	15,735,059	9,595,025	1,379,024	4,761,010
Public	44,675,392	11,610,472	7,401,246	890,939	3,318,287
Research universities — very high research activity	30,017,465	7,863,789	4,995,218	586,986	2,281,585
Private	22,521,145	4,124,587	2,193,779	488,085	1,442,723
Research universities — very high research activity	17,860,100	3,001,686	1,367,581	416,640	1,217,465
2015	68,566,890	16,608,089	10,411,219	1,351,638	4,845,232
Public	45,428,226	12,135,590	7,926,385	840,151	3,369,054
Research universities — very high research activity	30,866,665	8,307,825	5,391,189	558,486	2,358,150

Fiscal year, institution type, and Carnegie classification	All R&D expenditures	Institutional funds[a]			
		Total	Institutionally financed research	Cost sharing	Unrecovered indirect costs
Private	23,138,664	4,472,499	2,484,834	511,487	1,476,178
Research universities — very high research activity	18,320,160	3,245,663	1,585,157	435,686	1,224,820
2016	71,833,308	17,974,962	11,471,087	1,430,833	5,073,042
Public	47,147,814	12,727,952	8,302,999	891,283	3,533,670
Research universities — very high research activity	31,841,684	8,480,727	5,510,803	579,533	2,390,391
Private	24,685,494	5,247,010	3,168,088	539,550	1,539,372
Research universities — very high research activity	19,407,892	3,858,251	2,154,612	453,452	1,250,187

[a] Excludes research funds spent from multipurpose accounts.

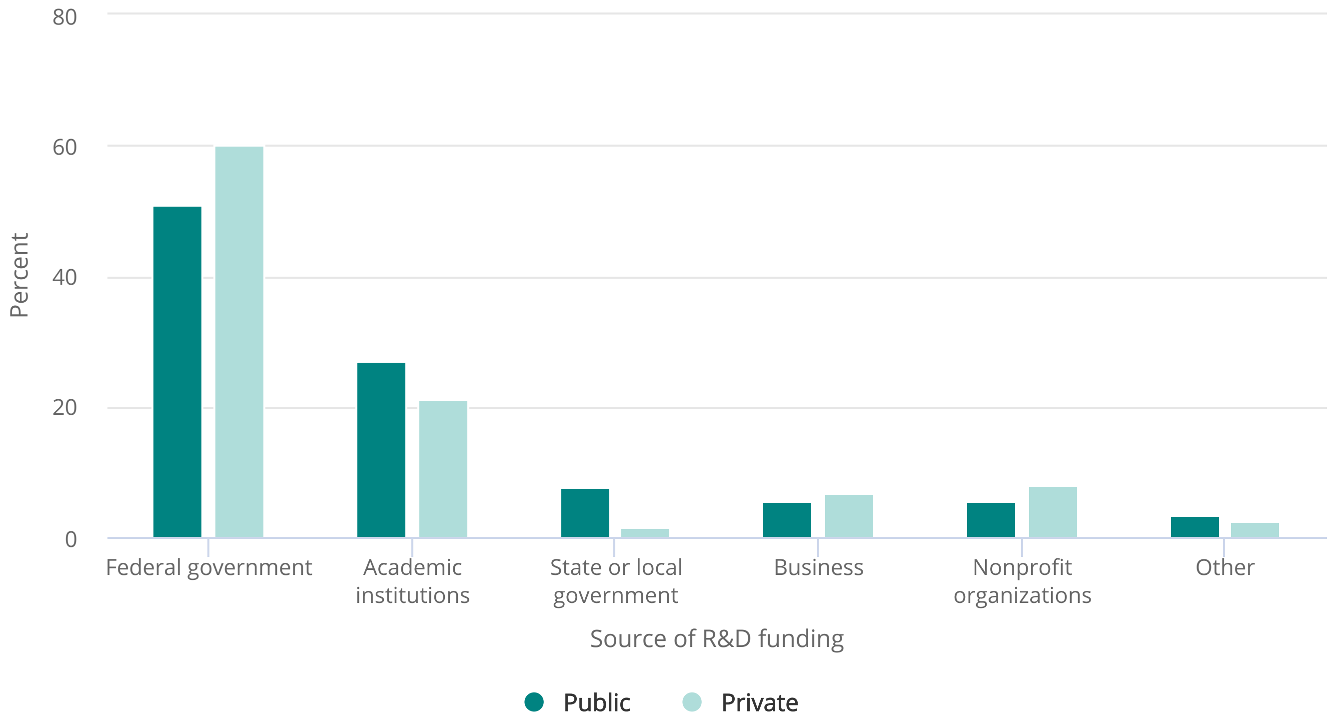
Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Higher Education Research and Development Survey (HERD).

Science and Engineering Indicators 2018

FIGURE 5-4

Sources of R&D funding for public and private academic institutions: FY 2016



Note(s)

Academic institutions' funds exclude research funds spent from multipurpose accounts.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Higher Education Research and Development Survey (HERD), FY 2016. See Appendix Table 5-2.

Science and Engineering Indicators 2018

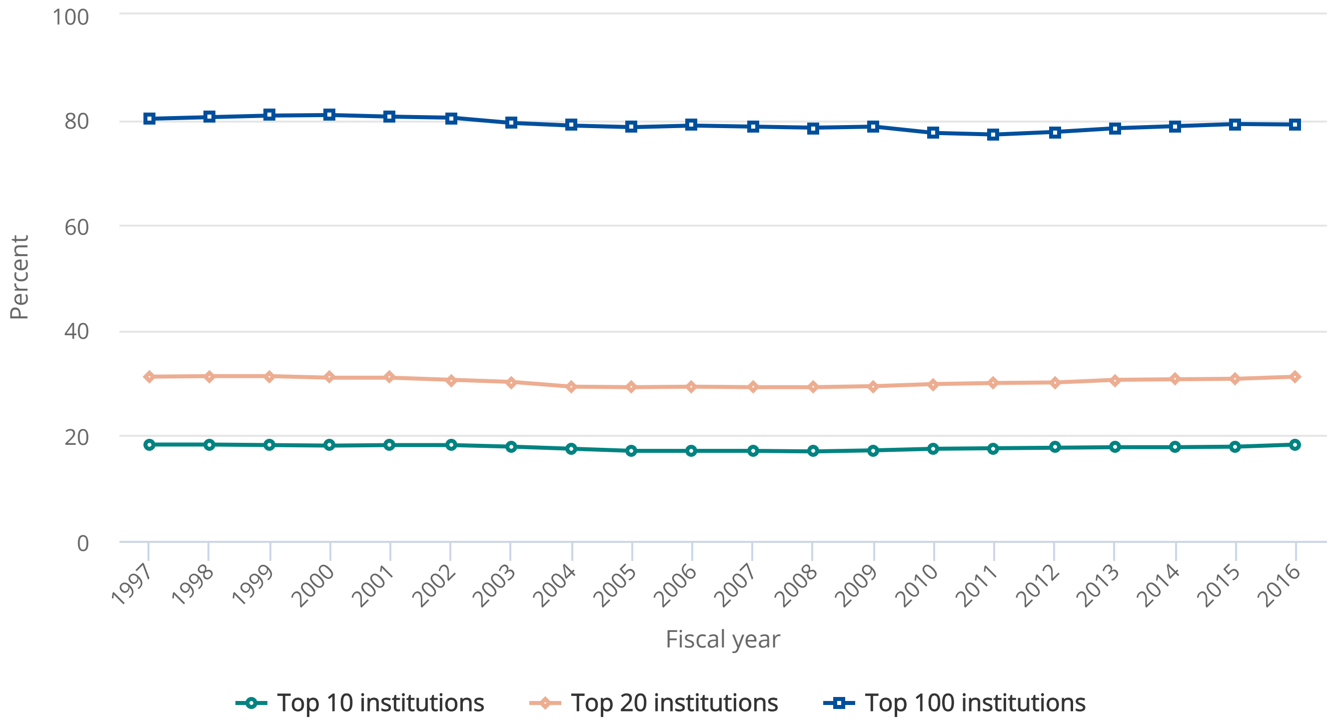
Distribution of R&D Funds across Academic Institutions

Academic R&D expenditures are highly concentrated in a relatively small number of institutions. In 2016, out of approximately 3,000 baccalaureate-, master's-, and doctorate-granting institutions, 640 reported spending at least $1 million on R&D.[17] The top-spending 20 institutions accounted for more than 30% of total academic R&D spending in 2016, and the top-spending 100 institutions accounted for just under 80%. The relative shares of the large research universities have been remarkably stable over the past two decades (Figure 5-5).

The more numerous public institutions account for a significant share of overall academic R&D spending (Appendix Table 5-2). Among the top 100 universities and colleges in academic R&D expenditures in 2015, approximately two-thirds were public, and one-third was private (Appendix Table 5-6).

FIGURE 5-5

Share of academic R&D, by institution rank in R&D expenditures: FYs 1997–2016



Note(s)

Totals for FYs 1996–2002 represent R&D expenditures in S&E fields only. Beginning in FY 2003, totals include R&D expenditures in S&E fields and non-S&E fields. However, from FY 2003 through FY 2009, some institution totals may be lower-bound estimates because the National Science Foundation did not attempt to estimate for nonresponse on non-S&E R&D expenditures before FY 2010.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Higher Education Research and Development Survey (HERD). See Appendix Table 5-6.

Science and Engineering Indicators 2018

Collaboration via Pass-Through Funding

In recent years, pass-through funding arrangements for collaborative projects among universities and other institutions have continued to grow in similar fashion to overall academic R&D spending. In 2016, public universities and colleges provided $2 billion in pass-through funds to other educational institutions and an additional $1.5 billion to other subrecipients. Their private counterparts provided $1.1 billion in pass-through funding to other higher education entities and about the same amount ($1 billion) to other subrecipients. Public universities received just under $2 billion in pass-through funds from other educational institutions and an additional $2.8 billion from other entities. Their private counterparts received $1.1 billion in pass-through funds from other higher educational institutions and about the same amount (just over $1 billion) from other entities. In a reflection of federal initiatives to encourage collaborative research, the large majority (over 80%) of pass-through funding arrangements are federally financed (Appendix Table 5-7).

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[1] The academic R&D totals presented here exclude expenditures at the federally funded research and development centers (FFRDCs) associated with universities. Those expenditures are tallied separately and discussed in Chapter 4. Nevertheless, the FFRDCs and other national laboratories (including federal intramural laboratories) play an important role in academic research and education, providing research opportunities for students and faculty at academic institutions, often by providing highly specialized, shared research facilities.

[2] This total represents the reported total R&D performance of the 640 institutions that reported at least $1 million in R&D expenditures during their previous fiscal year. It varies slightly from a similar total reported in Chapter 4, which removes the approximately $3 billion in pass-through funds that are double-counted in the HERD totals because such funds are counted by the universities initially receiving the money and by the universities to which the funds are passed. Also, the Chapter 4 total presents calendar-year approximations based on fiscal-year data. The 640 institutions accounted for 99.8% of the total R&D expenditures reported for FY 2016.

[3] In this chapter, the terms *universities and colleges*, *schools*, *higher education*, and *academic institutions* are used interchangeably.

[4] For a more complete discussion of these concepts, see the Chapter 4 Glossary. Chapter 4 provides further detail on federal obligations for academic R&D, by character of work.

[5] Starting in 2010, the HERD Survey asked institutions to categorize their R&D expenditures as *basic research*, as *applied research*, or as *development*; prior surveys had asked how much total S&E R&D the institution performed and requested an estimate of the percentage of the institution’s R&D expenditures devoted to basic research. By only mentioning basic research, the survey question may have caused some respondents to classify a greater proportion of their activities in this category. The 2010 question provided definitions and examples of the three R&D categories to aid institutions in making more accurate assignments. In debriefing interviews, institutional representatives cited the changes in the survey question as the most important factor affecting their somewhat lower estimates of the amount of basic research that institutions performed. The explicit inclusion of clinical trials and research training grants and the addition of non-S&E R&D may also have contributed.

[6] The academic R&D reported here includes separately accounted-for R&D and related recovered indirect costs. It also includes committed cost sharing and institutional estimates of unrecovered indirect costs associated with externally funded R&D projects. *Indirect costs* are general expenses that cannot be associated with specific research projects but pay for things that many research projects use collectively at an academic institution. Two major components of indirect costs exist: (1) *facilities-related costs*, such as the depreciation, maintenance, and operation of facilities used for research; and (2) *administrative costs*, including expenses associated with financial management, institutional review boards, and environment, health, and safety management. Some indirect costs are recovered as a result of indirect-cost proposals that universities submit based on their actual costs from the previous year.

[7] The federal government funds a much smaller proportion of R&D in non-S&E fields (27% in 2016) than it does in S&E fields (56% in 2016).

[8] See National Research Council (2012) for a report exploring ways to strengthen the partnership between government, universities, and industry in support of national goals.

[9] For more information on federally funded higher education R&D expenditures funded by ARRA, see Table 2016 5-3 [NSB 2016]).

[10] Statistics on R&D performance can differ depending on whether the reporting is by R&D performers—in this case, academic institutions—or R&D funders. Reasons for this difference are discussed in the Chapter 4 sidebar 💬 Tracking R&D Expenditures: Disparities in the Data Reported by Performers and Sources of Funding.

[11] *Unrecovered indirect costs* are calculated as the difference between an institution's negotiated indirect cost rate on a sponsored project and the amount that it recovers from the sponsor. *Committed cost sharing* is the sum of the institutional contributions required by the sponsor for specific projects (*mandatory cost sharing*) and the institutional resources made available to a specific project at the discretion of the grantee institution (*voluntary cost sharing*).

[12] Various challenges exist with measuring institutionally financed research. For some universities, including some with very high research activity, their accounting systems or administrative practices do not enable them to separate the R&D component of multipurpose accounts. Because HERD measures only spending that is fully budgeted as R&D, for these institutions, reported institutional funds are less than the full amount of academic R&D that their schools fund.

[13] Life sciences also feature prominently in research space and equipment, field of degree for S&E doctorate holders, and research publications.

[14] For more information on interdisciplinary research, see the Chapter 5 sidebar "Interdisciplinary Research: Strategic Implications and Measurement Challenges" (NSB 2016:5-31–5-32).

[15] See also the Chapter 2 section Trends in Higher Education Expenditures and Revenues for a discussion of average per-student financial flows at public and private institutions.

[16] In 1991, the Office of Management and Budget capped reimbursement of administrative costs at 26% of total direct costs. As a result, actual unrecovered indirect costs at public and private universities may be somewhat higher than the amounts reported in HERD. The share of unrecovered indirect costs within the institutional funds total has declined in recent years due to the growth in the amount of direct institutional funding for research; the total amount of unrecovered indirect costs has remained relatively stable for both public and private institutions over the past 5 years.

[17] An additional 262 institutions reported spending less than $1 million on academic R&D in FY 2015. These institutions received a shorter version of the survey questionnaire and are not represented in this chapter.

Infrastructure for Academic R&D

Physical infrastructure is an essential resource for the conduct of R&D. Traditionally, the capital infrastructure for R&D consisted primarily of research space (e.g., laboratories, computer rooms) and instrumentation. Accordingly, the square footage of a designated research space and counts of instruments have been the principal indicators of the status of research infrastructure.

Advances in information technology have brought significant changes to the methods of scientific research and the infrastructure necessary to conduct R&D. The technologies, human interfaces, and associated processing capabilities resulting from these innovations are often called *cyberinfrastructure.* The value of research facilities, research equipment, and cyberinfrastructure to the academic R&D infrastructure is highlighted in the sections that follow.

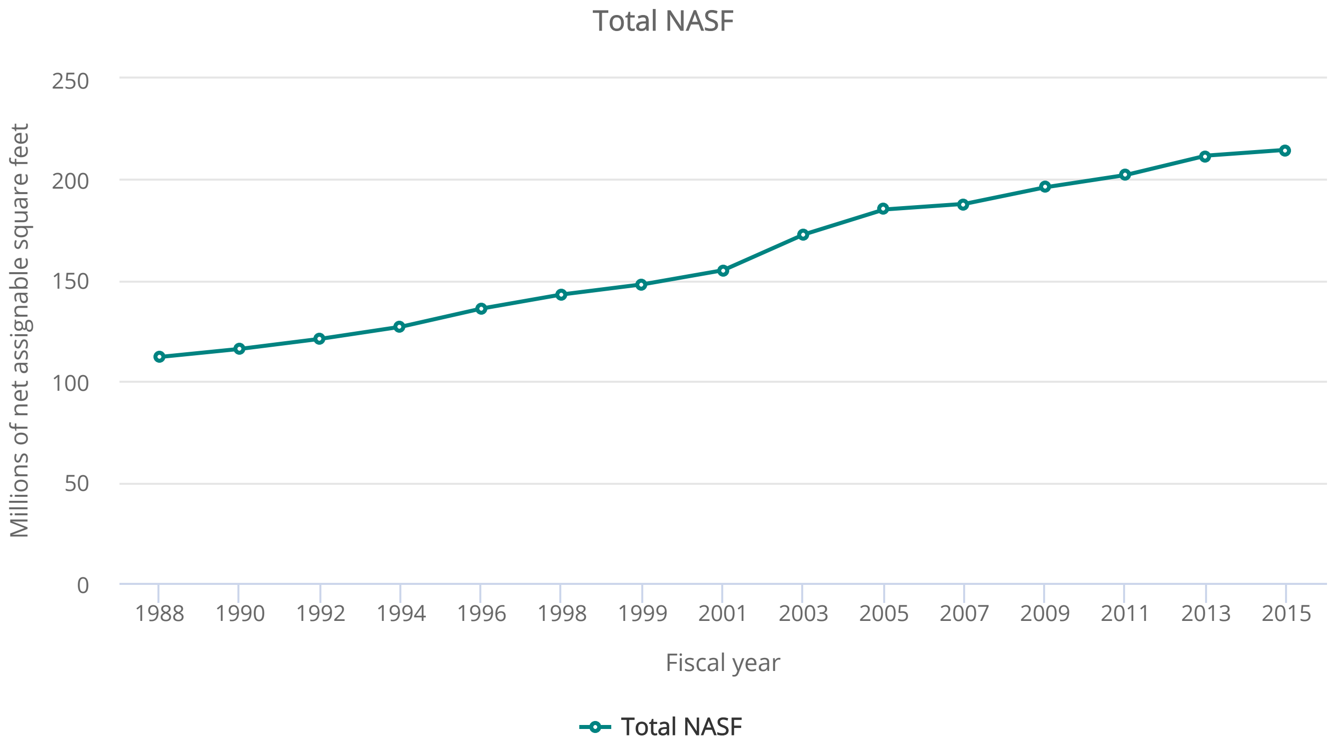
Research Facilities

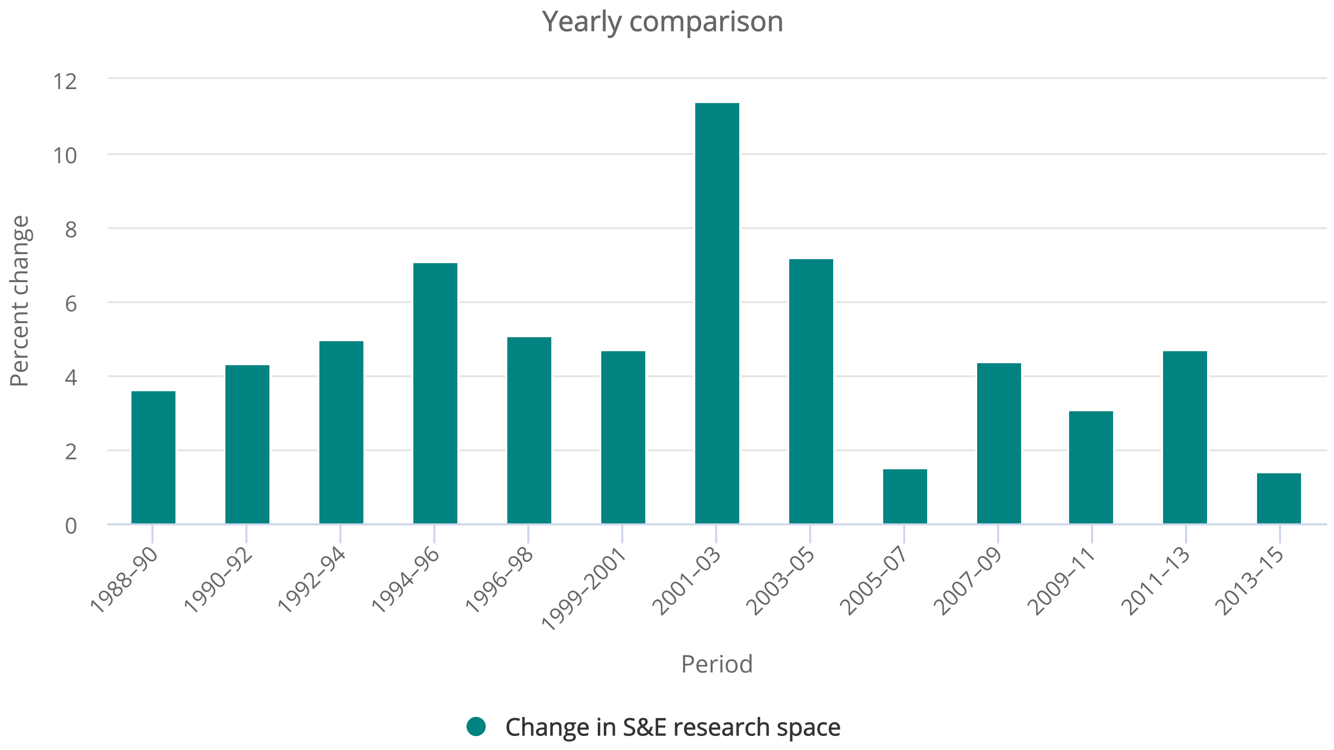
Research Space

Research-performing universities and colleges in the United States had 214.7 million net assignable square feet (NASF) of research space available at the end of 2015 (Appendix Table 5-8).[1] This was 1.4% greater than the NASF at the end of 2013, which was the lowest 2-year percentage increase since data collection began in 1988. Since 2005, the average biennial growth rate (3%) in research space has been less than half of the average biennial growth rate from 1996 to 2005 (7.1%) (Figure 5-6).

FIGURE 5-6

Change in S&E research space in academic institutions, by 2-year period: FYs 1988–2015





NASF = net assignable square feet.

Note(s)

The biennial survey cycle ran on even years from 1988 to 1998 and on odd years from 1999 to 2013.

Source(s)

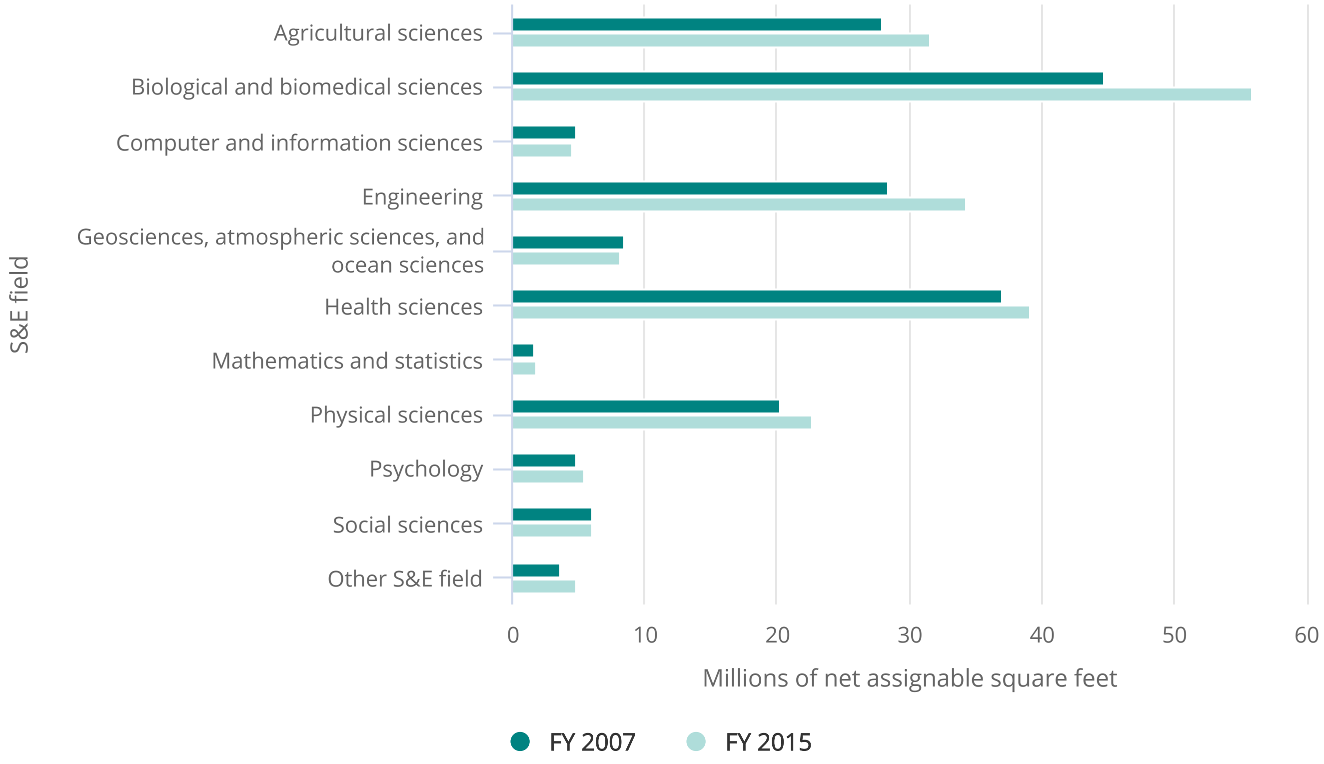
National Science Foundation, National Center for Science and Engineering Statistics, Survey of Science and Engineering Research Facilities.

Science and Engineering Indicators 2018

The biological and biomedical sciences continued to account for the largest share (26%) of academic research space in 2015. In this field, there was a 2.3% decline in research space between 2013 and 2015, compared with an 8.5% average growth biennially from 2007 to 2013 (Figure 5-7; Appendix Table 5-8).[2] The health sciences (18%), engineering (16%), agricultural sciences (13%), and physical sciences (11%) comprised the next largest shares of S&E research space. Research space in the smaller S&E fields increased by almost 4% from 2013 to 2015, with no single field showing a net loss of space. Engineering is the only major field where total research space increased consistently from 2007 to 2015. This is similar to the trend in R&D expenditures over the same period, when the only major fields with continuous growth in expenditures were engineering and geosciences, atmospheric sciences, and ocean sciences (see Appendix Table 5-5).

FIGURE 5-7

Research space at academic institutions, by S&E field: FYs 2007 and 2015



Note(s)

Natural resources and conservation is included with agricultural sciences for FY 2015. These fields were combined prior to FY 2015.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Survey of Science and Engineering Research Facilities. See Appendix Table 5-8.

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In 2015, 80% of research space was reported by academic institutions as being in superior or satisfactory condition (Table 5-9).[3] Sixteen percent of space required major renovations within the next 2 years, while the remaining 4% required replacement. These percentages have changed very little over the past decade.[4]

Between 76% and 84% of research space was rated as either superior or satisfactory across all but two major fields in 2015. Of research space in the computer and information sciences, 91% (4.5 million square feet) was rated as superior or satisfactory, while 72% of space in the natural resources and conservation field (3.5 million square feet) was similarly rated.

TABLE 5-9

Condition of S&E research space in academic institutions, by field: FY 2015

(Percent of net assignable square feet)

Field	NASF (millions)[a]	Condition (% NASF)			
		Superior	Satisfactory	Requires renovations	Requires replacement
All research space	210.9	35	45	16	4
Agricultural sciences	27.6	26	50	19	5
Biological and biomedical sciences	54.6	40	42	14	4
Computer and information sciences	4.5	50	41	7	2
Engineering	34.1	35	45	16	4
Geosciences, atmospheric sciences, and ocean sciences	8.1	30	47	17	6
Health sciences	38.4	40	43	14	4
Mathematics and statistics	1.8	30	54	15	2
Natural resources and conservation	3.5	29	43	19	9
Physical sciences	22.2	32	44	18	5
Psychology	5.4	34	45	18	4
Social sciences	5.9	25	55	17	3
Other	4.8	43	38	14	5

NASF = net assignable square feet.

[a] Includes NASF located at only those institutions that also rated the condition of their space. Consequently, this table accounts for approximately 3.8 million fewer NASF than other tables.

Note(s)

Detail may not add to total because of rounding. Condition was assessed relative to the use of the current research program.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Survey of Science and Engineering Research Facilities, FY 2015.

Science and Engineering Indicators 2018

New Construction

New research space is added each year by starting new construction projects and repurposing existing space. Similarly, some space is withdrawn from use through decommissioning and repurposing. The net result has been an increase in research space for more than two decades. As part of this process, academic institutions broke ground on 5.2 million square feet of new S&E research space construction projects in 2014–15, which was 21% less than the construction space started in 2012–13 (6.6 million square feet) (▦ Table 5-10). This continued a trend dating to 2002–03, where smaller amounts of new research space construction have been reported for five of the last six survey cycles. Construction projects for the biological and biomedical sciences (1.5 million square feet), engineering (1.0 million square feet), and the health sciences (1.0 million square feet) accounted for two-thirds of new research space construction started in 2014 or 2015.

TABLE 5-10

New construction of S&E research space in academic institutions, by field and time of construction: FYs 2006–17

(Millions of net assignable square feet and percent share of total new construction)

Field	Started in FY 2006 or FY 2007	Started in FY 2008 or FY 2009	Started in FY 2010 or FY 2011	Started in FY 2012 or FY 2013	Started in FY 2014 or FY 2015	Planned to start in FY 2016 or FY 2017
Net assignable square feet (millions)						
All fields	8.8	9.9	8.1	6.6	5.2	9.6
Agricultural sciences	0.5	0.4	0.4	0.4	0.4	0.5
Biological and biomedical sciences	2.9	3.5	2.0	2.0	1.5	2.3
Computer and information sciences	0.6	0.3	0.1	0.2	0.1	0.2
Engineering	1.3	2.1	1.3	1.4	1.0	1.5
Geosciences, atmospheric sciences, and ocean sciences	0.3	0.1	0.3	0.2	0.2	0.4
Health sciences	1.7	1.9	2.8	1.6	1.0	2.6
Mathematics and statistics	*	*	*	*	*	*
Natural resources and conservation	na	na	na	na	*	*
Physical sciences	0.7	0.9	0.6	0.6	0.7	1.0
Psychology	0.1	0.3	0.1	*	0.1	0.1
Social sciences	0.1	0.2	0.1	0.1	*	0.3
Other	0.7	0.3	0.3	0.1	0.2	0.7
Research animal space[a]	1.0	0.8	0.6	0.7	0.5	na
Share of total new construction square feet (%)						
All fields	100.0	100.0	100.0	100.0	100.0	100.0
Agricultural sciences	5.7	4.0	4.9	6.1	7.7	5.2

Field	Started in FY 2006 or FY 2007	Started in FY 2008 or FY 2009	Started in FY 2010 or FY 2011	Started in FY 2012 or FY 2013	Started in FY 2014 or FY 2015	Planned to start in FY 2016 or FY 2017
Biological and biomedical sciences	33.0	35.4	24.7	30.3	28.8	24.0
Computer and information sciences	6.8	3.0	1.2	3.0	1.9	2.1
Engineering	14.8	21.2	16.0	21.2	19.2	15.6
Geosciences, atmospheric sciences, and ocean sciences	3.4	1.0	3.7	3.0	3.8	4.2
Health sciences	19.3	19.2	34.6	24.2	19.2	27.1
Mathematics and statistics	*	*	*	*	*	*
Natural resources and conservation	na	na	na	na	*	*
Physical sciences	8.0	9.1	7.4	9.1	13.5	10.4
Psychology	1.1	3.0	1.2	*	1.9	1.0
Social sciences	1.1	2.0	1.2	1.5	*	3.1
Other sciences	8.0	3.0	3.7	1.5	3.8	7.3
Research animal space[a]	11.4	8.1	7.4	10.6	9.6	na

* = > 0 but < 50,000 net assignable square feet. na = not applicable; see notes.

[a] Research animal space is listed separately and is included in individual field totals.

Note(s)

S&E fields and their disciplines were revised in FY 2015. Specifically, "Agricultural sciences and natural resources sciences" has been split into "Agricultural sciences" and "Natural resources and conservation." "Physical sciences" and its subfields “Earth, atmospheric, and ocean sciences” and “Astronomy, chemistry, and physics” are now reported under "Geosciences, atmospheric sciences, and ocean sciences" and "Physical sciences," respectively. Data were not collected separately for "Natural resources and conservation" before the FY 2015 survey and are included in the "Agricultural sciences" field for earlier cycles. Data are not collected on planned new construction of research animal space. Detail may not add to total because of rounding. Research animal space is listed separately and is included in individual field totals.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Survey of Science and Engineering Research Facilities.

Academic institutions initiated new construction in all fields during 2014 and 2015, although the growth rate of new construction projects slowed over the past decade. These institutions anticipated that an additional 9.6 million square feet of new research space construction would be started in 2016 or 2017. This is the highest projected total since 10.3 million square feet were planned for 2010 and 2011. However, not all planned projects are started during the projected time frame because of various factors, such as changing budgets and priorities. In 2013, academic institutions reported 8.8 million square feet of planned new research space construction for 2014 or 2015. However, the actual amount reported in 2015 for that period was 5.2 million square feet—59% of what was planned. Data from the previous two cycles of the Survey of Science and Engineering Research Facilities indicate that 80% of planned new research space was started within the anticipated time frames.

Twenty-two percent of the nation's 570 research-performing colleges and universities (126 institutions) initiated new construction of S&E research space in 2014–15, with estimated completion costs of $5.7 billion (Appendix Table 5-9).[5] Although the new construction costs were an estimated 5.4% greater than projects started in 2012–13, they were lower than the amounts reported in every other 2-year period since 1998–99.

Academic institutions provide the majority of funds for construction of new research space, typically accounting for more than 60% of the cost (Appendix Table 5-9).[6] For the construction of new research space initiated in 2014–15, 64% of the funding came from institutions' internal sources, 20% from state and local governments, and the remaining 16% from the federal government. Although the $905 million of federal support is the most since data collection began for 1986–87, more than 60% of that funding was slated for the Facility for Rare Isotope Beams at Michigan State University. The facility is projected to be complete in 2022.[7]

Repair and Renovation

Academic institutions expended $4.1 billion on major repairs and renovations of S&E research space in 2014–15 (Appendix Table 5-10).[8] They anticipated another $3.9 billion in costs for planned repair and renovation of research space with start dates in 2016–17. More than $902 million were planned to improve space in biological and biomedical sciences as well as more than $884 million for improvements to health and clinical sciences space. In addition to these slated improvements, academic institutions reported $4.9 billion in repair and renovation projects from their institutional plans that were not yet funded or scheduled to start in 2016–17. Almost $4 billion in further needed improvements were identified that were not actually included in their institutional plans.

The total backlog of deferred improvements was greater than all projects started or planned for 2014–17. The costs for deferred repairs and renovations have consistently been greater than those started or planned for similar cycles in the past. This is due in part to the longer time frames of institutional plans, which often run beyond 5 years, and to the fact that the total backlog also accounts for projects not included in institutional plans.

In contrast to new construction, spending on repairs and renovations increased biennially since the 1990s, except for a dip in 2008–09. Federal funding for repairs and renovations fluctuated greatly over this period. State government funding grew continually for two decades to a peak of $855 million in 2010–11 before declining by more than 40% to $503 million in 2014–15. Academic institutions have been the main contributors to research space repair and renovation funding, typically providing 70% or more of the funds. With the latest dip in federal and state government support for these projects, institutional funds accounted for 86% of research space repair and renovation funding for projects started in 2014–15 (Appendix Table 5-11).[9]

Research Equipment

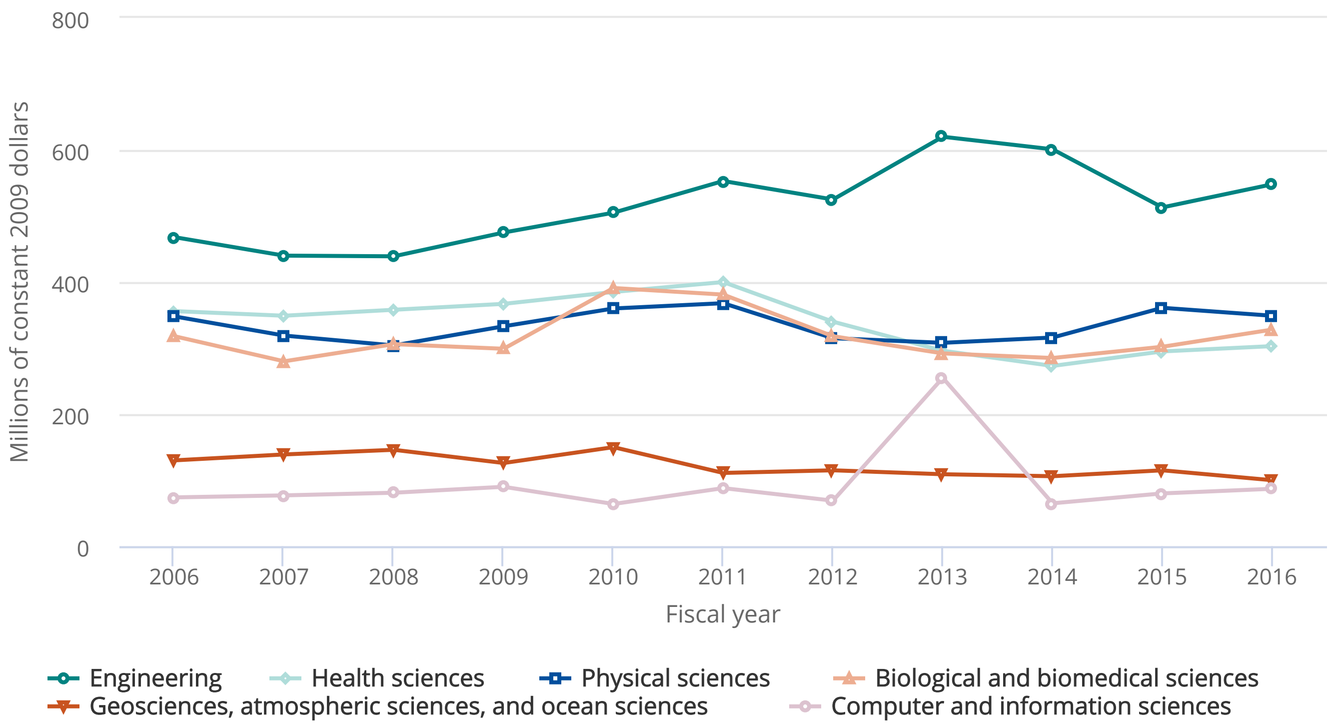
In 2016, universities spent about $2.1 billion for movable equipment necessary for the conduct of academic S&E research projects (Appendix Table 5-12).[10] This spending accounted for 3.1% of the $67.7 billion total academic S&E R&D expenditures. Annual equipment spending increased 2.2%, on average, from 2014 to 2016 when adjusted for inflation, after fluctuating by 10%–11% during the previous 3 years. The 2016 total is slightly below average, in constant dollars, for the 2002–16 period.

Research equipment expenditures continue to be concentrated in just three fields, which accounted for 87% of the 2016 total: life sciences (40%), engineering (29%), and physical sciences (18%). The shares for these three fields have consistently accounted for about 80% or more of total equipment expenditures, although the combined shares have been at or near the highest on record for the past several years (Appendix Table 5-12).

When adjusted for inflation, the 2016 level of equipment spending in engineering was 7% greater than the 2015 total. The 2013 and 2014 totals were the highest levels of engineering equipment expenditures reached in decades, while the 2016 level was above average for the 2006–16 period (Figure 5-8). Total science equipment spending was 19% lower than the high point reached in 2004 in constant dollars (Appendix Table 5-12).

FIGURE 5-8

Current fund expenditures for S&E research equipment at academic institutions, by selected S&E field: FYs 2006–16



Note(s)

Gross domestic product deflators come from the U.S. Bureau of Economic Analysis and are available at https://www.bea.gov/national/, accessed 10 February 2016.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Higher Education Research and Development Survey (HERD). See Appendix Table 5-12.

Science and Engineering Indicators 2018

Unlike funding for new construction of research space, which relies heavily on institutional funds, most academic research equipment funding typically comes from the federal government. These federal funds are received as part of research grants or as separate equipment grants. Prior to 2014, federal support for research equipment had not fallen below 50% since data were initially collected in 1981. The federal share of research equipment funding reached 63% as recently as 2011. In 2014, the federal government supported 45% of total academic S&E research equipment funding. This share ticked slightly higher in 2015, to 47%, but fell again to 45% in 2016 (Appendix Table 5-13).

The federal share of funding varies significantly by S&E field and subfield. Atmospheric sciences and meteorology (85%), physics (74%), and industrial and manufacturing engineering (69%) were the only fields receiving around 70% or more federal funding for R&D equipment, while two fields (political science and government, 13%; economics, 8%) received less than 20% federal support.

Cyberinfrastructure

Advances in computing technology and information technology have changed the nature of scientific research and the infrastructure for conducting it over the past three decades. Cyberinfrastructure includes resources such as high-capacity networks, which are used to transfer information, and data storage systems, which are used for short-term access or long-term curation. It may also involve high-performance computing (HPC) systems used to analyze data, create visualization environments, or facilitate remote use of scientific instrumentation (NSF 2012). Cyberinfrastructure helps researchers process, transfer, manage, analyze, and store large quantities of data.

Rapid changes in the field and the often decentralized nature of many research project requirements have made quantifying these resources very difficult. Many researchers access computing, storage, software, and networking resources on their own rather than through the resources their universities provide. Increasingly, academic institutions are centralizing their cyberinfrastructure resources to increase efficiency.

The Extreme Science and Engineering Discovery Environment (XSEDE) is part of a continuing federal effort to provide the academic research community with a range of HPC, networking, visualization, data storage, software, and support services. NSF announced the 5-year, $121 million project in 2011 as a partnership of 17 institutions supporting 16 supercomputers across the country, with the anticipation of expanding resources throughout the lifetime of the project (NSF 2011). XSEDE enabled more than 6,000 scientists to conduct research, at no added cost, from its initiation in 2011 through 2016.

Federal investment in cyberinfrastructure for academic, federal, and industry research gained visibility and momentum with the National Strategic Computing Initiative (NSCI), created by executive order of the president in 2015 (White House, Office of the Press Secretary 2015). The strategic plan, outlined in 2016, explained the initiative as

> a whole-of-Nation effort to sustain and enhance U.S. leadership in high-performance computing. The NSCI seeks to accomplish five strategic objectives in a government collaboration with industry and academia: (1) accelerate the successful deployment and application of capable exascale computing; (2) ensure that new technologies support coherence in data analytics as well as simulation and modeling; (3) explore and accelerate new paths for future computing architectures and technologies, including digital computing and alternative computing paradigms; (4) holistically expand capabilities and capacity of a robust and enduring HPC ecosystem; and (5) establish an enduring public-private collaboration to ensure shared benefit across government, academia, and industry. (NSCI Executive Council 2016:3)[11]

The strategic plan highlighted the critical roles of academia, government, and industry in the process. The goal is to ensure access to HPC resources for academic and industry researchers so that the United States can maintain its science and technology leadership role.

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[1] Research space here is defined as the space used for sponsored R&D activities at academic institutions and for which there is separate budgeting and accounting. Research space is measured in net assignable square feet (NASF); this is the sum of all areas on all floors of a building assigned to, or available to be assigned to, an occupant for a specific use, such as research or instruction. NASF is measured from the inside faces of walls. Multipurpose space that is partially used for research is prorated to reflect the proportion of time and use devoted to research. Totals exclude research space at FFRDCs associated with universities.

[2] Changes were made to some S&E fields between FYs 2005 and 2007, which include several field name changes, the order in which fields are listed in survey questions, and the disciplines included in several fields. Consequently, there is a break in data continuity at the field level from FYs 2005 to 2007.

[3] For the FY 2015 Survey of Science and Engineering Research Facilities, 570 academic institutions were asked to identify the percentage of research NASF (including research animal space) that fell into each of the four following condition categories in the next 2 years (FYs 2016–17): *superior condition*—suitable for the most scientifically competitive research in this field over the next 2 years; *satisfactory condition*—suitable for continued use over the next 2 years for most levels of research in this field but may require minor repairs or renovation; *requires renovation*—will no longer be suitable for current research without undergoing major renovation within the next 2 years; *requires replacement*—should stop using space for current research within the next 2 years.

[4] Tables containing ratings of research space condition for past facilities surveys can be found at https://nsf.gov/statistics/srvyfacilities/.

[5] On the FY 2014 HERD, 570 academic institutions reported at least $1 million in R&D expenditures. These institutions were used to create the frame for the FY 2015 Survey of Science and Engineering Research Facilities. As noted earlier in the chapter, 640 institutions reported at least $1 million in R&D expenditures on the FY 2015 HERD.

[6] *Institutional sources* include universities' operating funds, endowments, private donations, tax-exempt bonds and other debt financing, and indirect costs recovered from federal and nonfederal sources.

[7] Adjusted for inflation, the previous highest total of federal funding for new construction of S&E research space reported in this survey was $829 million (in inflation-adjusted 2015 dollars) during FYs 1990–91. For information on federal funding of the Facility for Rare Isotope Beams, see Howell (2014) and https://frib.msu.edu/index.php.

[8] Only projects whose prorated cost was estimated to be $250,000 or more for at least one S&E field were included.

[9] Data from 1986 to 2015 for new construction and repair and renovation funding are available in (NSF/NCSES 2017). The tables at the NSF/NCSES website display more years because they have a limited breakdown of type of institutional control (public versus private).

[10] Because of rising capitalization thresholds, the dollar threshold for inclusion in the equipment category has changed over time. Generally, university equipment that costs less than $5,000 would be classified under the supplies cost category.

[11] Exascale refers to computing systems capable of producing at least a billion billion calculations per second or floating operations per second.

Doctoral Scientists and Engineers in Academia

Academically employed research doctorate holders in S&E hold a central role in the nation's academic R&D enterprise. Through the R&D they undertake, S&E doctorate holders produce new knowledge and contribute to marketplace innovation. They also teach and provide training opportunities for young people who may then go on to earn S&E doctorates; some of these young doctorate holders will then train the next generation of scientists and engineers, while others will contribute through their employment in business or in government.

This section examines trends in the size and demographic composition of the doctoral S&E academic workforce and its deployment across institutions, positions, and fields. The workforce includes those with a research doctorate in science, engineering, or health who are employed in 2- or 4-year colleges or universities,[1] including medical schools and university research institutes, in the following positions: full and associate professors (referred to as *senior faculty*); assistant professors (referred to as *junior faculty*); postdoctorates (postdocs); other full-time positions, such as instructors, lecturers, adjunct faculty, research associates, and administrators; and part-time positions of all kinds. Unless otherwise specified, these individuals earned their doctorate at a U.S. university or college. Particular attention is paid to the component of this workforce that is more focused on research, including those employed in postdoc positions and researchers receiving federal support. A central message of this section is that, whether looked at across 15–20 years or across four decades, the demographic composition of the academically employed S&E workforce, like the S&E workforce overall, has changed substantially. There also have been noteworthy changes in the types of positions or job titles held by S&E doctorates employed at academic institutions.

Longer-term comparisons (from 1973 to 2015) are made to illustrate fluctuations over multiple decades and trends that continue to unfold. Shorter-term comparisons (generally from the early to mid-1990s to 2015) are made to illustrate what the past two decades have brought forth.[2] Comparisons over the 12-year period from 2003 to 2015 are used in the discussion of minorities in the academically employed workforce because the race and ethnicity categories before this time are not directly comparable to those from 2003 forward. Because individuals in faculty and nonfaculty positions both conduct R&D, much of the discussion addresses the overall academic employment of U.S.-trained S&E doctorate holders, regardless of position or rank. However, at various points, full-time faculty and those who work outside of the full-time faculty population are discussed separately. (For an overview of the data sources used, see sidebar 💬 Data on Doctoral Scientists and Engineers in Academia, and see sidebar Foreign-Trained Academic S&E Doctoral Workforce.)

SIDEBAR

Data on Doctoral Scientists and Engineers in Academia

Data on academically employed research doctorate holders are drawn primarily from the Survey of Doctorate Recipients (SDR), a biennial National Science Foundation (NSF) survey of individuals, including those born in foreign countries, who received their research doctorate in an S&E field from a U.S. institution. This survey provides the most comprehensive data available on these individuals. Data are provided on educational background, employment status, occupation, and demographic characteristics. Unless specifically stated, estimates of S&E doctorates come from the SDR. The latest survey is available at https://www.nsf.gov/statistics/srvydoctoratework/#qs.

In 2015, the SDR was expanded with a much larger sample to produce better estimates of employment outcomes by the detailed field of degree taxonomy used in the Survey of Earned Doctorates, the SDR's sampling frame. As in prior years, underrepresented populations were oversampled, including women and certain racial and ethnic groups (blacks, Hispanics, and Native Americans or American Indians). As a result, more precise estimates by finer categories of field are available for all U.S.-trained S&E doctorate holders and for subpopulations that historically have been underrepresented in S&E employment. The expanded SDR also provides full representation of foreign-born S&E doctorate holders, especially those who became naturalized citizens, because the sampling frame included all respondents who had earned a degree from a U.S. academic institution since 1960, regardless of their residency in 2015.

Because the SDR covers only U.S.-trained individuals, it substantially undercounts postdoctoral researchers (postdocs), most of whom were trained outside the United States, and provides no estimates of foreign-trained doctoral holders in other positions in academia, such as full-time faculty. Two other surveys referenced in this section supplement SDR data to provide coverage of the foreign-trained doctorate recipients. To obtain more complete counts of postdocs, this section supplements SDR's estimated counts with counts provided in the Survey of Graduate Students and Postdoctorates in Science and Engineering, an annual survey cosponsored by NSF and the National Institutes of Health. The latest survey is available at https://nsf.gov/statistics/srvygradpostdoc/.

To provide more data on the role of foreign-trained doctorate holders in academic R&D, this section draws from NSF's National Survey of College Graduates (NSCG). Although the NSCG provides less detail on academic employment, it provides estimates of the foreign-trained component. See the sidebar Foreign-Trained Academic S&E Doctoral Workforce for data on foreign-trained individuals' presence in academic employment. The latest NSCG surveys are available at https://nsf.gov/statistics/srvygrads/.

SIDEBAR

Foreign-Trained Academic S&E Doctoral Workforce

U.S. universities and colleges have long employed S&E doctorate holders from foreign countries; most received their doctorate from a U.S. institution, but many earned it overseas. In 2015, approximately 68,000 foreign-trained S&E doctorate holders worked in U.S. higher education institutions. Approximately 70% of the foreign-trained doctorate holders were men, and 30% were women.

Because the Survey of Doctorate Recipients (SDR) uses a more restrictive definition of the research doctorate, some complications exist in comparing National Survey of College Graduates S&E fields with those from the SDR, particularly with regard to the life sciences and psychology. Taking these complications into consideration, the field distribution of the foreign-trained doctorate holders nonetheless varies from the U.S.-trained doctorate holders. The majority (just over 55%) of the foreign-trained individuals hold doctorates in the life sciences, while the majority of their U.S.-trained counterparts hold doctorates in the life sciences (34%) or the social sciences (18%) (▦ Table 5-B; Appendix Table 5-14). In 2015, female foreign-trained S&E doctorate holders were largely concentrated in the life sciences, whereas their male counterparts had large concentrations in the life sciences and physical sciences (▦ Table 5-B).

Foreign-trained doctorate holders have a substantial presence in conducting academic R&D, with about 90% reporting that research was their primary or secondary work activity in 2015 and more than one-half (52%) reporting support from federal grants and contracts. A smaller percentage of foreign-trained S&E doctorate holders is heavily engaged in teaching. In 2015, about 28% reported that teaching was their primary or secondary work activity (▦ Table 5-C).

TABLE 5-B

Foreign-trained S&E doctorate holders employed in academia, by degree field and sex: 2015

(Number)

Degree field	Total	Male	Female
Full-time positions			
All fields	64,000	46,000	18,000
Physical sciences	16,000	15,000	s
Computer and mathematical sciences	6,000	4,000	s
Life sciences	36,000	22,000	14,000
Social sciences and psychology	3,000	2,000	s
Engineering	3,000	3,000	s
Part-time positions			
All fields	4,000	2,000	2,000

s = suppressed for reasons of confidentiality and/or reliability.

Note(s)

Detail may not add to total because of suppression. Numbers are rounded to the nearest 100.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2017) of the 2015 National Survey of College Graduates (NSCG).

Science and Engineering Indicators 2018

TABLE 5-C

Foreign-trained S&E doctorate holders employed in academia, by research and teaching focus: 2015

(Percent)

Field	Federal support	R&D	Teaching
Full-time positions			
All fields	51.6	90.6	28.1
Physical sciences	31.3	93.8	25.0
Computer and mathematical sciences	33.3	83.3	50.0
Life sciences	66.7	91.7	19.4
Social sciences and psychology	s	66.7	66.7
Engineering	66.7	100.0	66.7
Part-time positions			
All fields	25.0	50.0	75.0

s = suppressed for reasons of confidentiality and/or reliability.

Note(s)

The percentage conducting R&D is the percentage of S&E doctorate holders reporting that their primary or secondary work activity is R&D. The percentage teaching is the percentage of S&E doctorate holders reporting that their primary or secondary work activity is teaching.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2017) of the 2015 National Survey of College Graduates (NSCG).

Science and Engineering Indicators 2018

Trends in Academic Employment of S&E Doctorate Holders

Academic employment of S&E doctorate holders grew over the past three decades and reached just under 400,000 in 2015. Of this total, the large majority—almost 330,000—were U.S. trained. Among these, about one-third (97,000) were born outside of the United States. This section will focus on the U.S.-trained segment because we have more detailed data available for this group. There was an increase of about 20,000 over the estimated employment numbers for the U.S.-trained segment in 2013 (Appendix Table 5-14). In recent decades, growth in the number of U.S.-trained doctoral scientists and engineers in the academic sector has been slower than the rate of growth in the business and government sectors, resulting in a decline in the academic sector's share of all U.S.-trained S&E doctorates, from 55% in the early 1970s to just under 50% in the mid-1990s to about 45% in 2015.

Trends in Types of Academic Positions Held

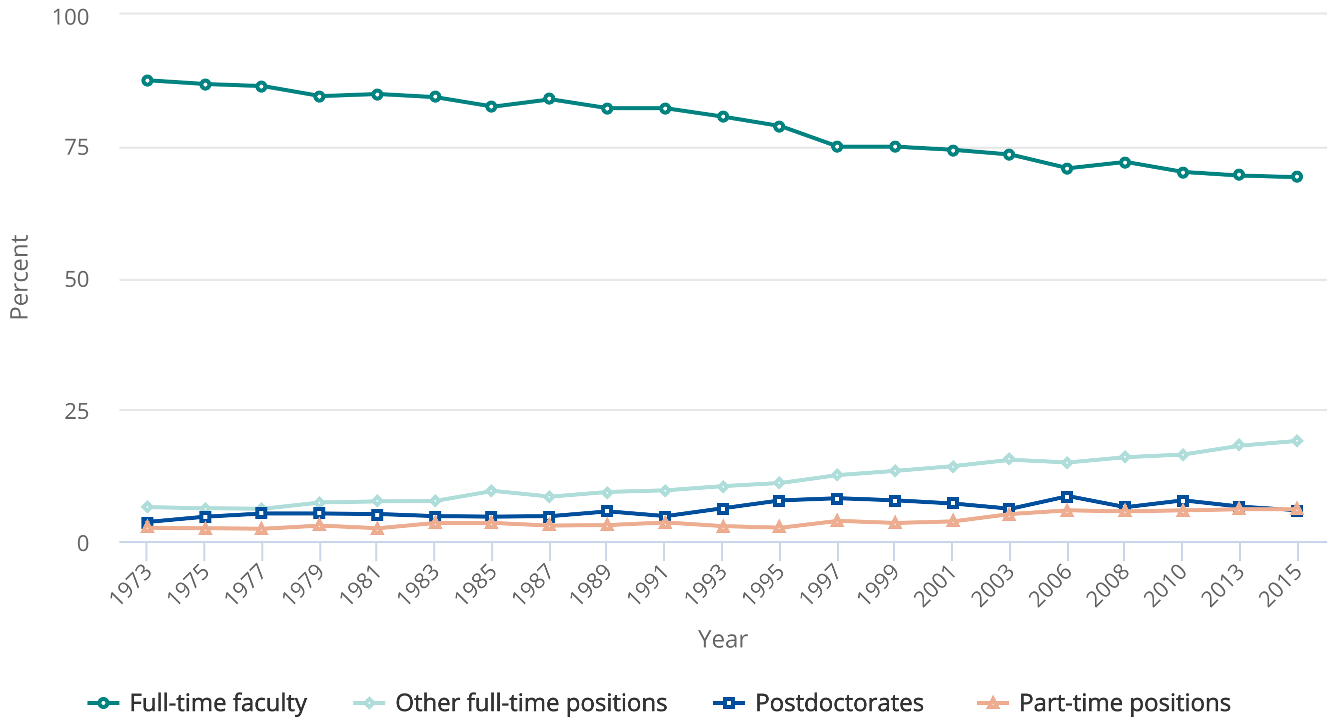
The doctoral academic workforce discussed in this section includes doctorate holders in S&E who are employed at 2- and 4-year colleges and universities, including medical schools and university research institutes. This workforce includes full and associate professors (senior faculty); assistant professors (junior faculty); postdocs; individuals in other full-time positions, such as instructors, lecturers, adjunct faculty, research associates, and administrators; and those employed in part-time positions of all kinds.

When looking at broad trends by position title over the past 40 years, very different patterns emerge. The total number of U.S.-trained, academically employed doctorate holders in S&E almost tripled over the period from 1973 to 2015, rising from 118,000 to just under 330,000, while the number of full-time faculty more than doubled (from 103,000 to 228,000) (Appendix Table 5-14). By contrast, the number of other full-time positions increased by more than 700% from 1973 to 2015, rising rapidly from a low base of 7,600 (6% of the total) to 62,600 (19% of the total).

Full-time faculty positions as senior or junior faculty continue to be the norm in academic employment, but S&E doctorate holders are increasingly employed in other types of positions (📊 Figure 5-9). The proportion of full-time faculty among all U.S.-trained, academically employed S&E doctorate holders fell from almost 90% (103,000 of 118,000 total) in the early 1970s to about 80% by the mid-1990s and then dropped further, to just under 70%, in 2015 (228,000 of 330,000 total). The decline in the proportion of full-time faculty was evident among doctorate holders in all S&E fields (Appendix Table 5-14). The proportion of part-time positions increased from 2% in 1973 (2,900) to 6% of all academic S&E doctorate holders in 2015 (19,800). However, an increase in the share of U.S.-trained postdoctoral positions in most years through 2006 has reversed.[3] From the early 1970s to 2015, the proportion of U.S.-trained postdocs increased from 4% in 1973 (4,200) to 9% in 2006 (23,300), then declined to 6% in 2015 (19,200). There has also been a decrease in the percentage of U.S.-trained doctorate holders in tenured positions.

FIGURE 5-9

S&E doctorate holders employed in academia, by type of position: 1973–2015



Note(s)

Academic employment is limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, medical schools, and university research institutes. Full-time faculty includes full, associate, and assistant professors and instructors (from 1973 to 1995) and full, associate, and assistant professors (from 1997 to 2015). Other full-time positions include positions such as research associates, adjunct appointments, instructors (from 1997 to 2015), lecturers, and administrative positions. Part-time positions exclude those held by students or retired people. Percentages may not add to 100% because of rounding.

Source(s)

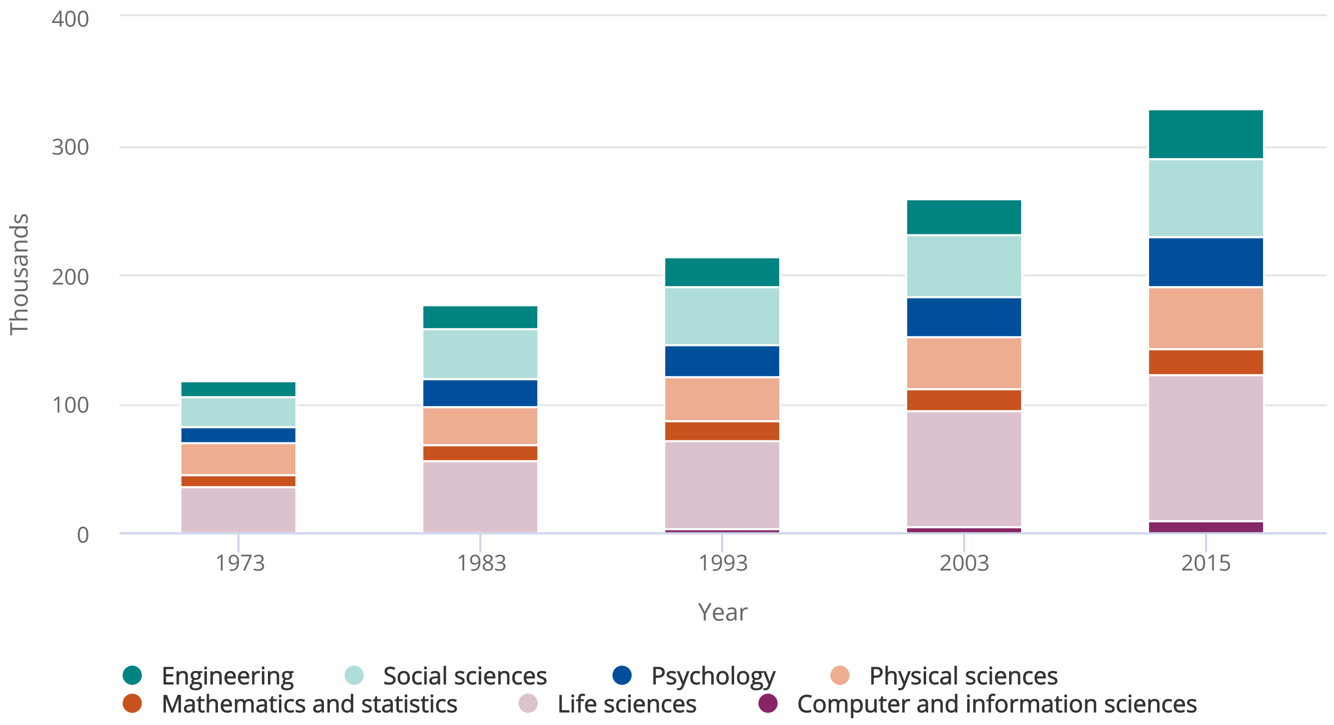
National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2017) of the 1973–2015 Survey of Doctorate Recipients (SDR).

Science and Engineering Indicators 2018

From the early 1970s through 2015, growth in the academic employment of life scientists, psychologists, and engineers was greater than for doctorate holders in other S&E fields (Figure 5-10). Starting from a very small base around 1980, there was also consistent, rapid growth in the number of computer and information scientists. Growth in academic employment slowed in the early to mid-1990s for social sciences, physical sciences, and mathematics and statistics. It has increased since then in social sciences and mathematics and statistics and, recently, in the physical sciences (Appendix Table 5-14). Similar to spending patterns discussed in the first section of this chapter, Spending for Academic R&D, the most recent decade saw greater growth in the number of engineers in academic employment than their peers in most fields of science, while hiring of computer and information scientists continued to grow rapidly from a small base (Figure 5-10).

FIGURE 5-10

S&E doctorate holders employed in academia, by field: Selected years, 1973–2015



Note(s)

Data for computer sciences are not available for 1973. Academic employment is limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, excluding those employed part time who are students or retired. Physical sciences include earth, atmospheric, and ocean sciences; life sciences include biological, agricultural, environmental, and health sciences. Numbers are rounded to the nearest 100.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2017) of the 1973–2015 Survey of Doctorate Recipients (SDR).

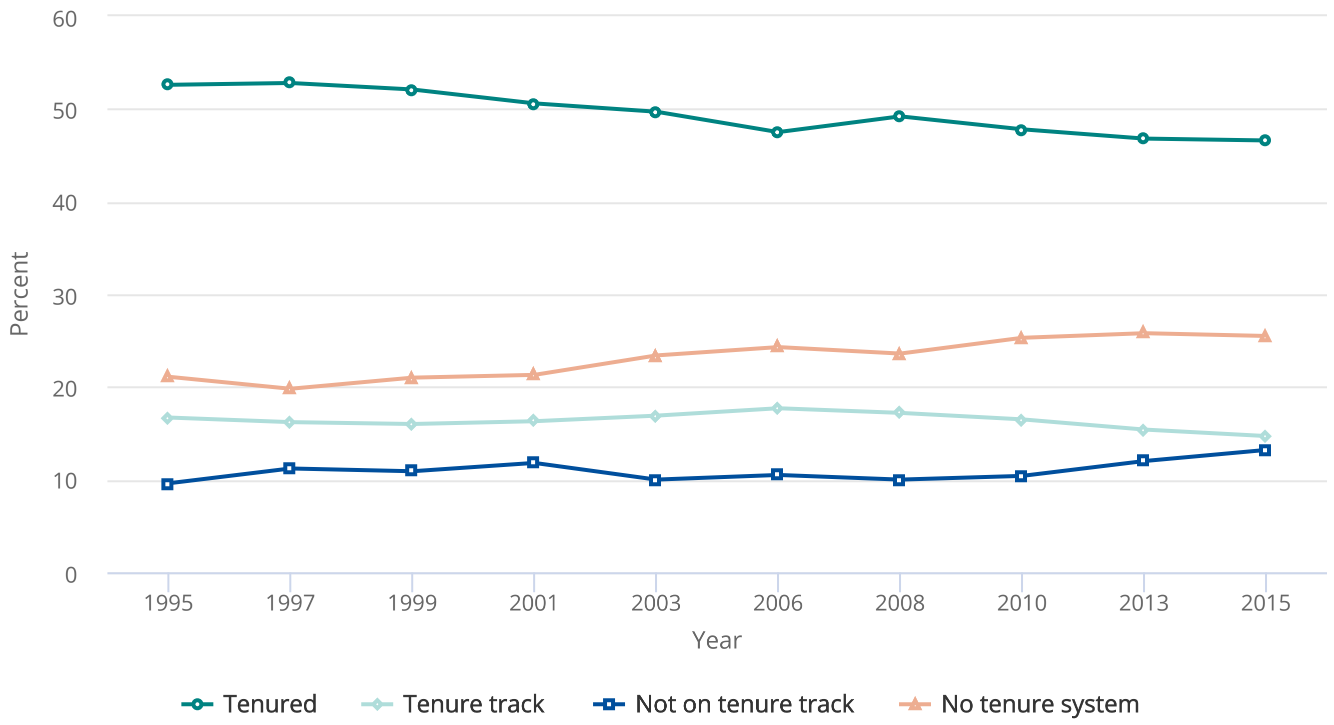
Science and Engineering Indicators 2018

Trends in Tenure Status

Among U.S.-trained S&E doctorate holders employed in academia, the proportion that has achieved tenure has diminished since 1995. In 1995, about 53% (118,000) of U.S.-trained S&E doctorate holders in academic employment held tenured positions; this decreased to 47% in 2015 (154,000) as nontenured positions of various types grew as a proportion of expanding overall doctoral academic employment (Figure 5-11).[4] Somewhat higher percentages of individuals in 1995 (17%; 37,000 individuals) as in 2015 (15%; 48,000 individuals) were untenured but on a tenure track.

FIGURE 5-11

Tenure status of S&E doctorate holders employed in academia: 1995–2015



Note(s)

Academic employment is limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, excluding those employed part time who are students or retired. No tenure system includes no tenure system for the position or no tenure system at the institution.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2017) of the 1995–2015 Survey of Doctorate Recipients (SDR).

Science and Engineering Indicators 2018

In 1995 and 2015, the distribution of tenured and tenure-track status varied by S&E field (Table 5-11). For those with doctoral degrees in life sciences (113,000 individuals in 2015; 71,600 in 1995), mathematics and statistics (21,000 individuals in 2015; 14,600 in 1995), or psychology (38,800 individuals in 2015; 26,100 in 1995), the percentage of tenured positions decreased from 1995 to 2015 by about 7–8 percentage points. For those with doctoral degrees in physical sciences (48,400 in 2015; 35,700 in 1995), social sciences (59,700 in 2015; 42,500 in 1995), or engineering (39,700 in 2015; 23,800 in 1995), there was a somewhat smaller decrease in the percentage of tenured positions of about 4–5 percentage points over this period. For those with a degree in computer and information sciences (9,100 in 2015; 3,100 in 1995), the percentage in tenured positions was higher in 2015 (54%) than in 1995 (41%) (Table 5-11 and Appendix Table 5-14).

TABLE 5-11

Tenure status, by field of S&E doctorate holders employed in academia: 1995 and 2015

(Percent)

Field of doctorate	1995			2015		
	Tenured	Tenure track	Others	Tenured	Tenure track	Others
All fields	52.6	16.7	30.7	46.6	14.7	38.7
Mathematical sciences	70.0	14.7	14.7	62.7	14.4	23.0
Social sciences	63.5	18.3	18.0	58.3	16.2	25.5
Computer and information sciences	40.6	43.8	15.6	53.8	20.9	25.3
Engineering	54.1	18.4	27.5	50.6	16.1	33.2
Physical sciences	48.2	11.5	40.0	44.4	12.2	43.4
Psychology	50.8	16.0	33.6	42.4	13.7	43.9
Life sciences	45.4	17.3	37.2	37.8	14.5	47.7

Note(s)

Academic employment is limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, medical schools, and university research institutes. Percentages may not add to 100% because of rounding. Others include S&E doctorate holders at institutions where no tenure is offered or there is no tenure for the position held.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2017) of the Survey of Doctorate Recipients (SDR).

Science and Engineering Indicators 2018

Comparing 1995 and 2015, the distribution of tenure-track positions by age group was fairly similar, but within each age group the tenured or nontenured status varied (Table 5-12). About the same proportion of doctorate holders in various age groups in 1995 and 2015 were in tenure-track positions. By contrast, in 2015, lower percentages of S&E doctorate holders at each age group were tenured, compared with 1995. For example, 19% of those 35–39 years of age held tenured positions in 2015 (9,100 individuals), compared with 25% in 1995 (9,200 individuals). For older cohorts, there were also large differences between 1995 and 2015 in tenured status. For example, 59% of those 50–54 years of age held tenured positions in 2015 (24,200 individuals), while 76% of those in that age range held tenured positions in 1995 (28,200 individuals). Reflecting the lifting of age restrictions on university faculty, there was a larger presence in the doctoral academic workforce of tenured faculty 65–75 years of age in 2015 (23,000; 7% of the total workforce) than in 1995 (6,000; 3% of the total workforce), making it difficult to compare changes in tenure status in this age range over time.

TABLE 5-12

Tenure status of S&E doctorate holders employed in academia, by age: 1995 and 2015

(Percent)

Age	1995			2015		
	Tenured	Tenure track	Others	Tenured	Tenure track	Others
Total all ages	52.6	16.7	30.7	46.6	14.7	38.7
Younger than 30	s	25.0	75.0	s	26.9	76.9
30–34	5.2	36.7	58.5	3.2	35.8	61.0
35–39	24.9	35.2	39.8	18.9	35.3	45.9
40–44	47.2	20.5	32.3	43.3	19.3	37.5
45–49	63.1	10.3	26.5	54.4	10.0	35.6
50–54	75.8	5.4	18.5	59.3	4.9	35.9
55–59	80.1	2.0	17.5	64.0	3.9	32.0
60–64	85.8	1.4	12.8	68.1	2.6	29.3
65–75	75.9	s	22.8	68.2	1.4	30.4

s = suppressed for reasons of confidentiality and/or reliability.

Note(s)

Academic employment is limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, medical schools, and university research institutes. Percentages may not add to 100% because of rounding. Others include S&E doctorate holders at institutions where no tenure is offered or there is no tenure for the position held.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2017) of the Survey of Doctorate Recipients (SDR).

Science and Engineering Indicators 2018

The reduction from 1995 to 2015 in tenured positions' share of total positions occurred across most (but not all) Carnegie classifications (see Chapter 2 sidebar Carnegie Classification of Academic Institutions for a discussion of Carnegie classifications). In 1995, an estimated 47% of academically employed S&E doctorate holders at the most research-intensive institutions (research I institutions) held tenured positions (42,300 individuals); this percentage decreased to 40% in 2015 (46,400 individuals). Reductions in share also occurred at less research-intensive institutions (research II institutions). However, at medical schools and medical centers, largely similar percentages of academically employed doctorate holders occupied tenured positions in 1995 (30%; 10,800 individuals) as in 2015 (27%; 14,200 individuals).[5] A similar trend was seen at baccalaureate institutions (58%, or 12,800 individuals, in tenured positions in 2015, compared with 61%, or 9,700 individuals, in 1995).

Just over one-third of academically employed doctorate holders earned their degree before 1995 (119,000). The remainder (210,000) are here considered early- to mid-career doctorate holders in that they earned their degree in 1995 or later. This younger cohort was less likely than the older group to be employed in tenured positions and more likely to hold positions outside of the tenure system. Overall, more than two-thirds of those who earned their doctorate before 1995 held tenured positions (85,700 individuals), while only one-third of the more recently degreed were tenured (67,900). Tenure status for the two groups varied somewhat by field (▦ Table 5-13).

TABLE 5-13

Tenure status of S&E doctorate holders employed in academia, by career stage and field of doctorate: 2015

(Percent)

Field of doctorate	Doctorate awarded before 1995			Doctorate awarded in 1995 or later		
	Tenured	Tenure track	Others	Tenured	Tenure track	Others
All fields	71.8	1.5	26.7	32.3	22.2	45.5
Physical sciences	66.7	1.0	32.3	29.4	19.7	50.9
Mathematics and statistics	86.5	1.1	11.2	44.6	24.0	31.4
Computer and information sciences	83.3	s	12.5	43.3	28.4	28.4
Life sciences	66.8	2.2	30.8	23.8	20.4	55.8
Psychology	59.2	2.8	38.0	32.7	20.0	47.3
Social sciences	80.0	0.9	18.7	44.6	25.5	29.6
Engineering	78.9	0.7	20.4	34.4	25.2	40.4

s = suppressed for reasons of confidentiality and/or reliability.

Note(s)

Academic employment is limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, medical schools, and university research institutes. Percentages may not add to 100% because of rounding. Others include S&E doctorate holders at institutions where no tenure is offered or there is no tenure for the position held.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2017) of the 2015 Survey of Doctorate Recipients (SDR).

Science and Engineering Indicators 2018

Women in the Academic S&E Workforce

The past 40 years have seen 10-fold growth in women's participation in the academic doctoral S&E workforce. In 1973, only about 11,000 U.S.-trained female S&E doctorates were employed in academia, contrasting sharply with about 123,000 in 2015. Over the past two decades alone, academic employment of women with S&E doctorates rose from about 52,000 in 1995 to 123,000 in 2015. Over the four decades, the number of their male counterparts almost doubled, growing from 107,000 to about 206,000 (Appendix Table 5-15).

These differential rates of increase are reflected in the steadily rising proportion of women with S&E doctorates in the academic workforce. Despite the impressive gain, women with S&E doctorates still account for a minority of the people employed in academia. Women constituted 37% of all U.S.-trained, academic S&E doctoral employment and 31% of full-time senior faculty in 2015, up from 9% and 6%, respectively, in 1973 (Appendix Table 5-15). Women's share of academic S&E employment increased markedly over time in all full-time position categories (Table 5-14). Until recently, women have held a noticeably larger proportion of junior faculty positions than senior ones, reflecting a trend over the past half-century in a rising proportion of doctoral degrees earned by women, coupled with their slightly greater propensity to enter academic employment. The proportion of women in all faculty ranks rose substantially between 1973 and 2015, reaching 25% of full professors, 40% of associate professors, and 43% of assistant professors (Figure 5-12). By contrast, women's share of part-time positions was similar in 1973 (48%) and 2015 (52%).

TABLE 5-14

Women as a percentage of S&E doctorate holders employed in academia, by position: Selected years, 1973–2015

(Percent)

Position	1973	1983	1993	2003	2015
All positions	9.1	15.0	21.9	30.3	37.4
Full-time senior faculty	5.8	9.3	14.2	22.8	30.9
Full-time junior faculty	11.3	23.5	32.2	39.7	42.5
Other full-time positions	14.5	23.1	30.2	34.8	43.9
Postdocs	14.3	30.1	30.8	38.0	42.7
Part-time positions	48.3	41.7	61.0	54.5	52.0

Note(s)

Academic employment is limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, medical schools, and university research institutes. Senior faculty includes full and associate professors; junior faculty includes assistant professors and instructors in 1973, 1983, and 1993; in 2003 and 2015, junior faculty includes assistant professors. Other full-time positions include positions such as research associates, adjunct appointments, instructors (in 2003 and 2015), lecturers, and administrative positions. Part-time positions exclude those employed part time who are students or retired.

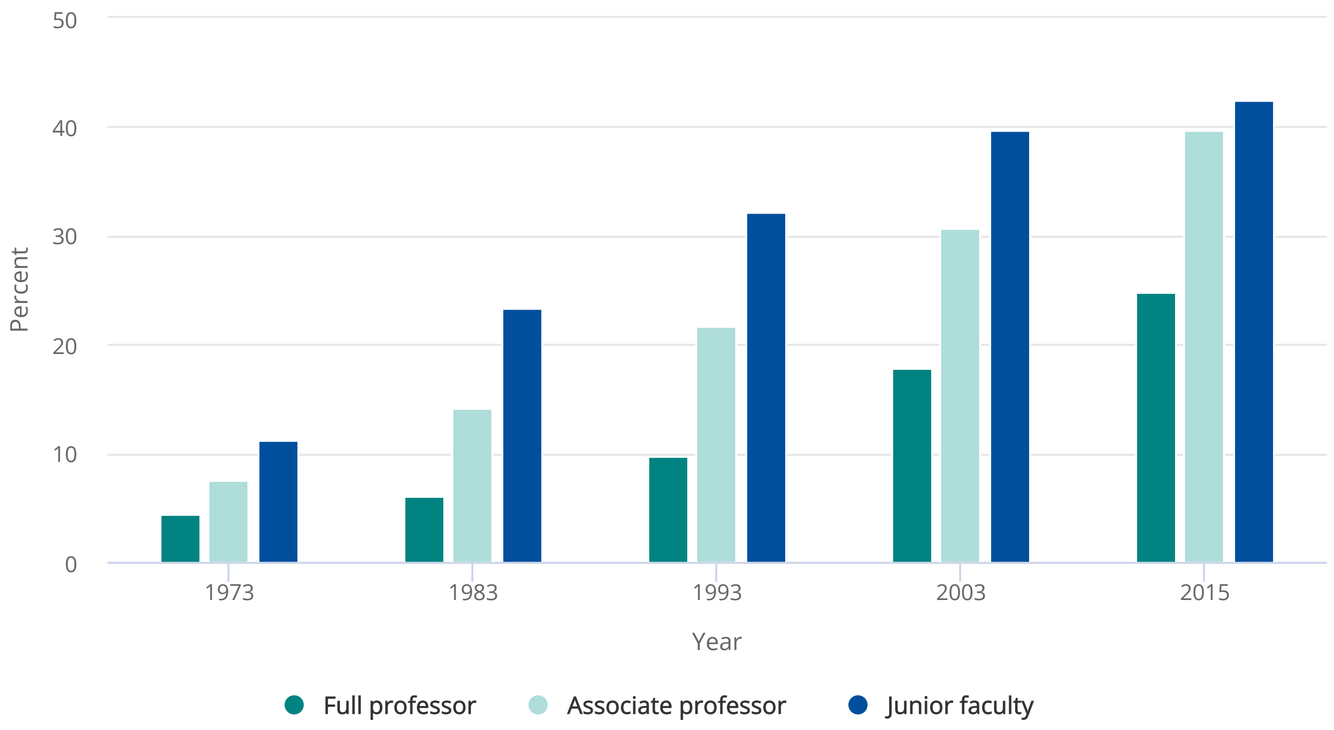
Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2017) of the 2003 and 2015 Survey of Doctorate Recipients (SDR).

Science and Engineering Indicators 2018

FIGURE 5-12

Women as a percentage of S&E doctorate holders employed full time in academia, by academic rank: Selected years, 1973–2015



Note(s)

Academic employment is limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, medical schools, and university research institutes, excluding those employed part time who are students or retired. Junior faculty includes assistant professors and instructors in 1973, 1983, and 1993; in 2003 and 2015, junior faculty includes assistant professors.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2017) of the 2003 and 2015 Survey of Doctorate Recipients (SDR).

Science and Engineering Indicators 2018

Also reflecting the long-term trend of a rising proportion of doctoral degrees earned by women is the fact that women constitute a much larger share of the younger cohort of academic doctorate holders degreed since 1995 (44%; 91,800) than their older counterparts degreed before 1995 (26%; 31,500). In 2015, the younger cohort of women constituted 34% of full professors and 43% of associate professors and assistant professors, while their older counterparts held 22% of full professorships, 32% of associate professorships, and 39% of assistant professorships (Figure 5-13).

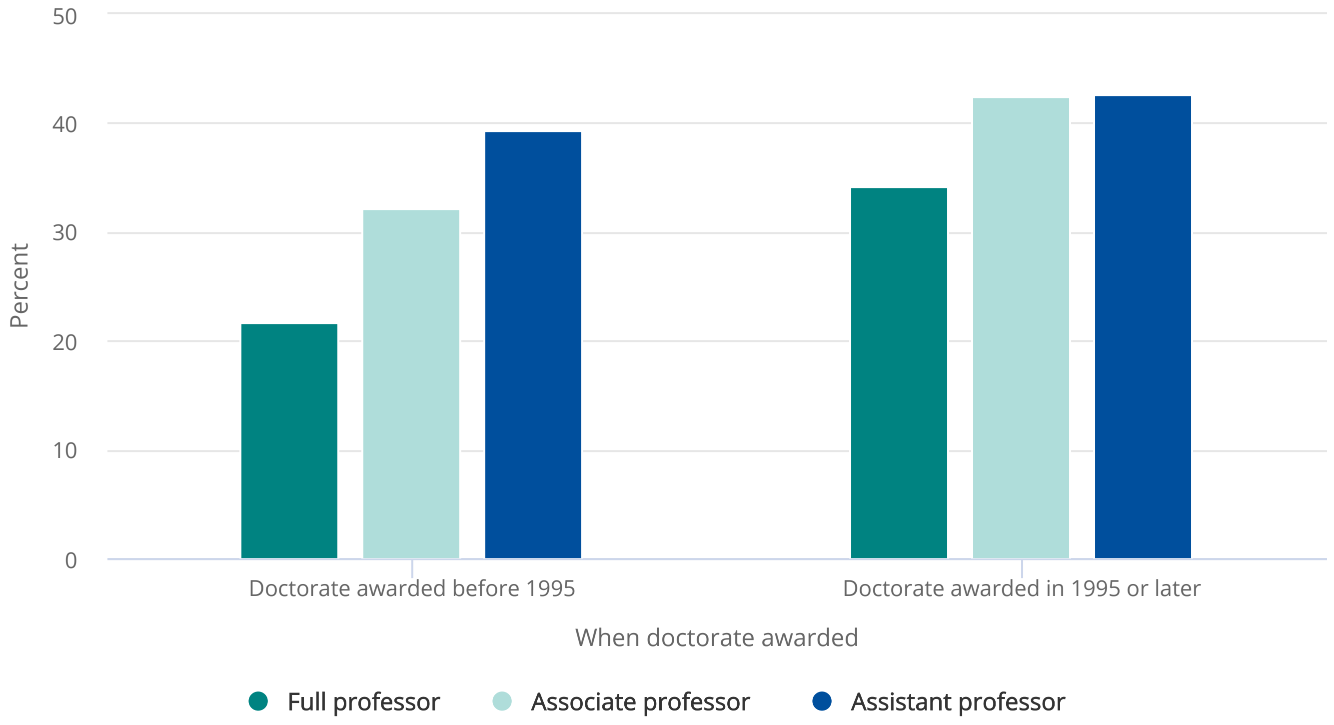
Women's presence varied across S&E fields. Women are relatively more concentrated in the life sciences, social sciences, and psychology, with correspondingly lower shares in engineering, physical sciences, mathematics and statistics, and computer and information sciences. Women's share of doctorate holders in each of these fields, however, grew during the

1973–2015 period (Appendix Table 5-15). Although, as noted previously, there has been an overall reduction over the past 20 years in the proportion of U.S.-trained S&E doctorate holders who have achieved tenure, the experiences of men and women have differed (Table 5-15). There were reductions over this period in the proportion of men in tenured positions across most S&E fields; the proportion of women, on the contrary, rose or remained similar.

Although a smaller proportion of women than men held tenured positions, among the younger cohort (those degreed since 1995), women held the majority of full-time faculty positions in psychology (58%) and were at parity with men in full-time faculty positions in the life sciences (about 50%).

FIGURE 5-13

Women as a percentage of younger and older S&E doctorate holders employed full time in academia, by academic rank: 2015



Note(s)

Academic employment is limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, medical schools, and university research institutes, excluding those employed part time who are students or retired.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2017) of the 2015 Survey of Doctorate Recipients (SDR).

Science and Engineering Indicators 2018

TABLE 5-15

Tenured S&E doctorate holders employed in academia, by sex and field: 1995 and 2015

(Percent)

Tenured	Total		Female		Male	
	1995	2015	1995	2015	1995	2015
All fields	52.6	46.6	34.5	37.2	58.3	52.3
Physical sciences	48.2	44.4	23.9	37.4	51.5	46.3
Mathematics and statistics	70.0	62.7	44.4	50.0	73.5	66.9
Computer and information sciences	40.6	53.8	33.3	47.4	42.3	55.6
Life sciences	45.4	37.8	30.4	29.6	52.0	44.8
Psychology	50.8	42.4	33.9	35.4	63.9	51.8
Social sciences	63.5	58.3	47.3	50.9	69.4	62.9
Engineering	54.1	50.6	25.0	40.0	56.3	53.0

Note(s)

Academic employment is limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, medical schools, and university research institutes, excluding those working part time because they are students or are retired.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2016) of the Survey of Doctorate Recipients (SDR).

Science and Engineering Indicators 2018

Minorities in the Academic S&E Workforce

Similar to women, members of underrepresented minority groups (i.e., blacks, Hispanics, and American Indians or Alaska Natives) have increased their presence in academic employment over time, but to a much lesser degree (Appendix Table 5-16).[6] Combined, these groups constituted 8.9% of total doctoral academic S&E employment in 2015, up from about 7.9% in 2003.[7] Underrepresented minorities held 8.6% of full-time faculty positions in 2015, up from 7.0% in 2003 and 1.9% in 1973 (Table 5-16). Compared with white and Asian or Pacific Islander S&E doctorate holders employed in academia, underrepresented minorities in 2015 were somewhat more concentrated in psychology and the social sciences and somewhat less so in the physical sciences and mathematics and statistics (Appendix Table 5-16).

TABLE 5-16

Underrepresented minorities as a percentage of S&E doctorate holders employed in academia, by position: Selected years, 1973–2015

(Percent)

Position	1973	1983	1993	2003	2015
All positions	2.0	3.7	5.0	7.9	8.9
Full-time faculty	1.9	3.6	5.0	7.0	8.6
Postdocs	2.4	4.8	4.5	7.0	8.9
Other positions	2.9	4.1	5.3	7.3	9.8

Note(s)

Underrepresented minorities include blacks or African Americans, Hispanics or Latinos, and American Indians or Alaska Natives. Because of changes in the survey questionnaire, data from 2003 to 2015 are not directly comparable with earlier years' data. Academic employment is limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, medical schools, and university research institutes. Faculty includes full, associate, and assistant professors plus instructors in 1973, 1983, and 1993. In 2003 and 2015, faculty includes full, associate, and assistant professors. Other positions include part-time positions and full-time positions such as research associates, adjunct appointments, instructors (in 2003 and 2015), lecturers, and administrative positions. Other positions exclude those employed part time who are students or retired.

Source(s)

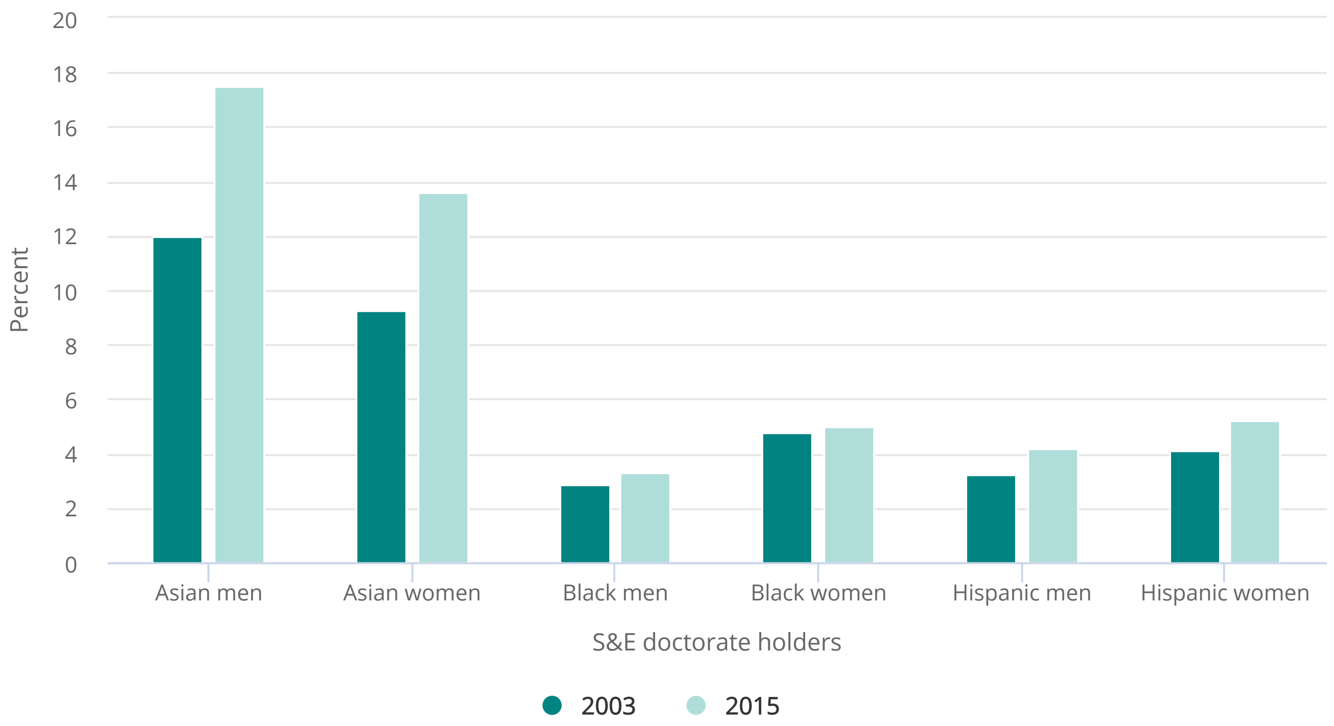
National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2017) of the 2003 and 2015 Survey of Doctorate Recipients (SDR).

Science and Engineering Indicators 2018

In 2003 and 2015, a slightly higher percentage of women (9.1% in 2003; 10.5% in 2015) than men (6.3% in 2003; 7.6% in 2015) who are underrepresented minorities held faculty positions in academic institutions.[8] Black and Hispanic women each held 4%–5% of full-time faculty positions held by women in both 2003 and 2015, while black and Hispanic men each held 3%–4% of such positions held by men (Figure 5-14). American Indian or Alaska Native men and women held about the same percentage of full-time faculty positions in 2003 and 2015 (less than 1%). Similar percentages (around 43%) of underrepresented minorities held tenured positions in 2003 and 2015; however, a smaller share held tenure-track positions in 2015 than in 2003 (Figure 5-15).

FIGURE 5-14

Black, Hispanic, and Asian S&E doctorate holders employed in academia as a percentage of full-time faculty positions, by sex: 2003 and 2015



Note(s)

Asian includes Native Hawaiian and Other Pacific Islander. Academic employment is limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, medical schools, and university research institutes.

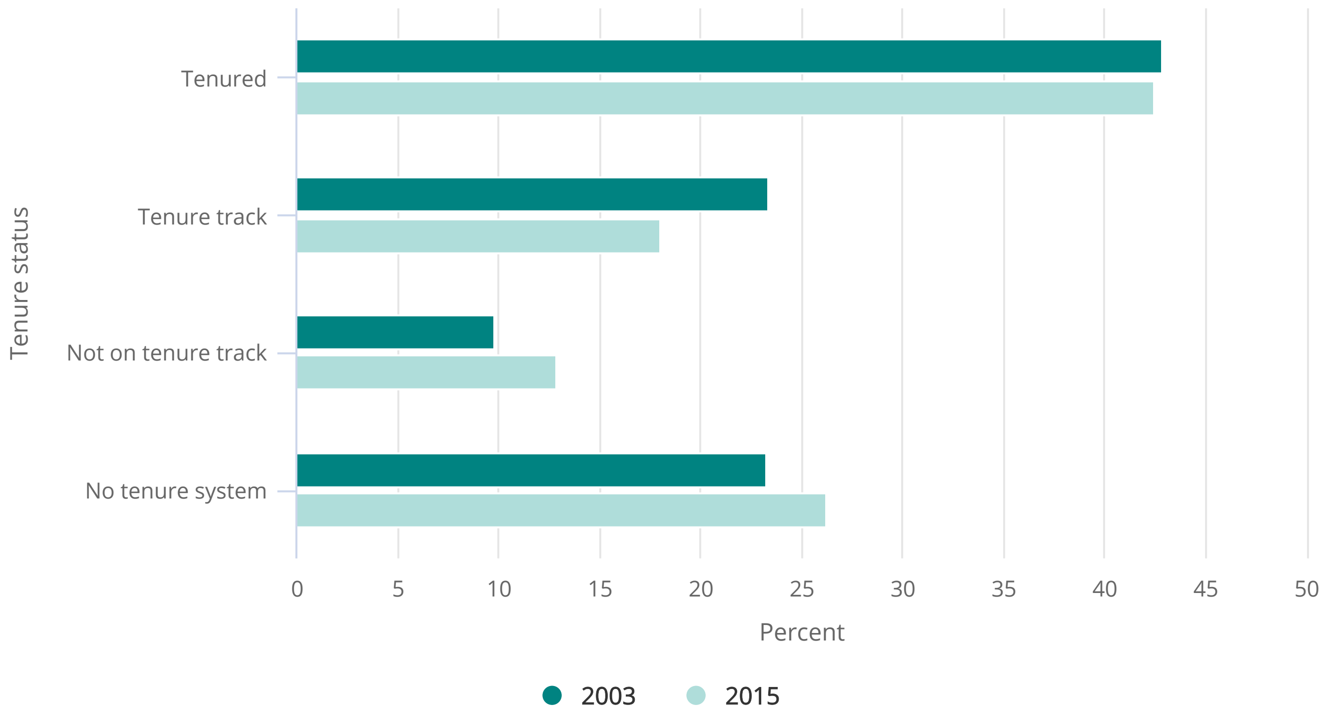
Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Survey of Doctorate Recipients (SDR).

Science and Engineering Indicators 2018

FIGURE 5-15

Tenure status of underrepresented minority S&E doctorate holders employed in academia: 2003 and 2015



Note(s)

Academic employment is limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, excluding those employed part time who are students or retired. No tenure system includes no tenure system for the position or no tenure system at the institution. Detail may not add to 100% due to rounding. Underrepresented minorities include blacks, Hispanics, and American Indians or Alaska Natives.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2017) of the 2003 and 2015 Survey of Doctorate Recipients (SDR).

Science and Engineering Indicators 2018

The proportion of Asians or Pacific Islanders employed in the S&E academic doctoral workforce grew dramatically over the past several decades, rising from 4% in 1973 to 13% in 2003 and 18% in 2015.[9] Asians or Pacific Islanders were heavily represented among those with degrees in engineering and computer and information sciences, where they constituted 32% and 33%, respectively, of these segments of the doctoral workforce in 2015. They constituted far smaller employment proportions among social scientists (10%) and psychologists (7%) (Appendix Table 5-16).

Unlike blacks or Hispanics, a higher percentage of male Asians or Pacific Islanders held full-time faculty positions than their female counterparts in 2003 and 2015. Asian or Pacific Islander men were in about 12.0% of male-occupied full-time faculty positions in 2003 and about 17.5% of these positions in 2015. Asian or Pacific Islander women held about 9.3% of female-occupied faculty positions in 2003 and about 13.6% in 2015 (Figure 5-14).

Comparing early- to mid-career doctorate holders with their counterparts in later stages of their academic careers evidences real change over time for underrepresented minorities in faculty employment. Those who received their doctorate within the past two decades (in 1995 or later) are more diverse in race and ethnicity than their older counterparts (who received their doctorate in 1994 or earlier). As noted previously, some 19,600 underrepresented minorities together held 8.6% of full-time faculty positions in 2015 (Table 5-16). However, a larger proportion of the younger cohort (10.2%; 13,500 individuals) than the older cohort (6.5%; 6,200 individuals) held such positions. Also, a higher share of female (11.8%; 6,400) than male (9.1%; 7,100) early- to mid-career doctorate holders in full-time faculty employment were underrepresented minorities.

Foreign-Born S&E Doctorate Holders in the Academic Workforce

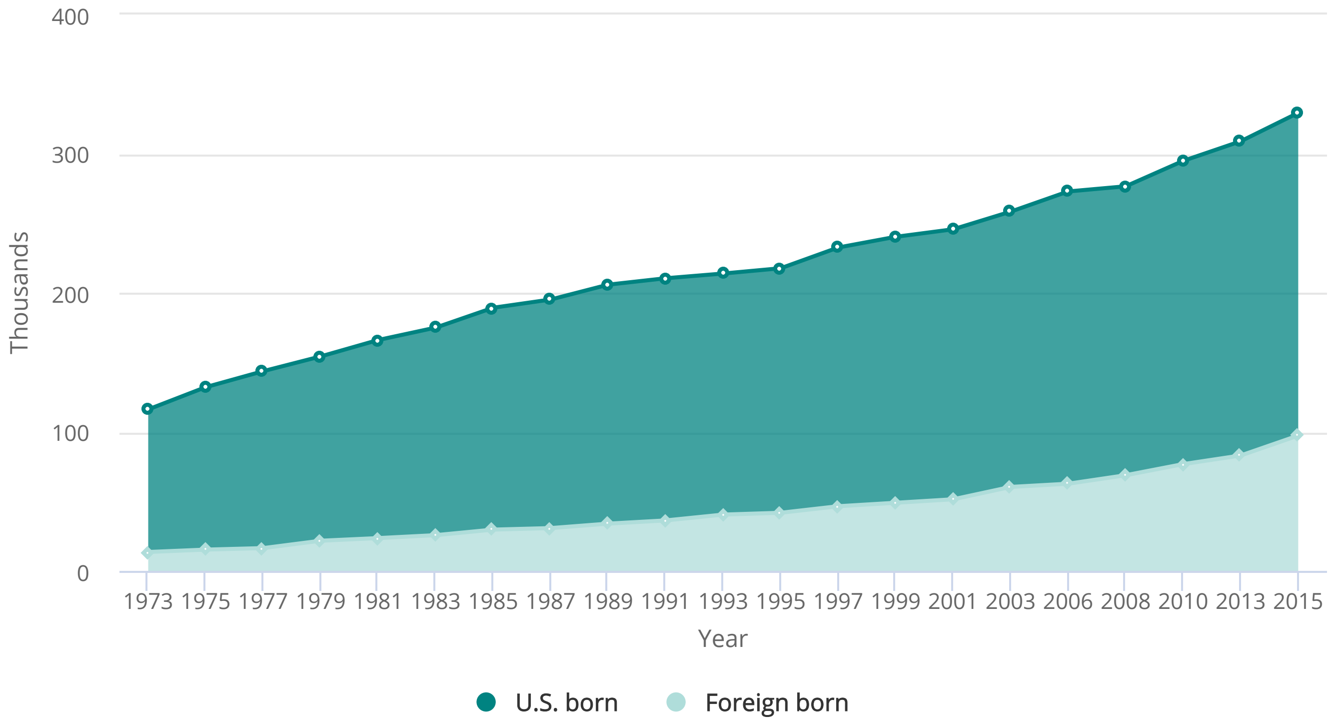
Academia has long employed foreign-born doctorate holders, many with doctorates from U.S. universities, as faculty and other staff. The following discussion focuses on foreign-born individuals who earned their S&E doctorate in the United States.

Academic employment of these foreign-born, U.S.-trained individuals has increased continuously since the 1970s, at a rate faster than that of their native-born counterparts, increasing the foreign-born proportion of academic S&E employment with U.S. doctorate training from 12% in 1973 to about 30% in 2015 (Figure 5-16).[10] Particularly high proportions are found in engineering (53%) and computer and information sciences (52%) (Appendix Table 5-17). Just over half (51%) of U.S.-trained postdocs were born overseas, compared with 28% of full-time faculty.[11]

In 2015, about 59,000 U.S.-trained Asian or Pacific Islanders were employed in universities and colleges (Appendix Table 5-16). Of these, 10% were native-born U.S. citizens; the rest were foreign born, with roughly equal proportions of naturalized U.S. citizens (44%) and noncitizens (46%). In 2015, Asians or Pacific Islanders represented 49% of the foreign-born, U.S.-trained S&E faculty employed full-time in the United States and 65% of the foreign-born, U.S.-trained S&E doctorate holders with postdoc appointments.

FIGURE 5-16

U.S.-trained S&E doctorate holders employed in academia, by birthplace: 1973–2015



Note(s)

Academic employment is limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, medical schools, and university research centers, excluding those employed part time who are students or retired. Numbers are rounded to the nearest 100.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2017) of the 1973–2015 Survey of Doctorate Recipients (SDR).

Science and Engineering Indicators 2018

Age Composition of the Academic Doctoral Workforce

The trend toward relatively fewer full-time faculty positions and relatively more other full-time and part-time positions is especially noteworthy because of the steady increase over the past 20 years in the proportion of full-time faculty positions that are held by those older than 60 years of age.

In 1995, individuals 60–75 years of age constituted about 11% of full-time faculty that year; this percentage increased to 25% in 2015.[12] In 1994, the Age Discrimination in Employment Act of 1967 (ADEA) became fully applicable to universities and colleges, prohibiting the forced retirement of faculty at any age. From this point through 2015, as more individuals born during the period of high birth rates from 1946 to 1964 (the "Baby Boomers") began to move through middle age into their 50s and 60s, the proportion of academically employed doctorate holders in the oldest age groups increased (▦ Table 5-17; Appendix

Table 5-18). (See Chapter 3 section Age and Retirement of the S&E Workforce for a discussion of the age profile and retirement patterns of the broader S&E workforce.)

TABLE 5-17

S&E doctorate holders employed in academia, by age: 1995 and 2015

(Percent)

Age	1995	2015
Younger than 40	29.0	26.1
40–59	61.0	51.7
60–75	10.0	22.3

Note(s)

Academic employment is limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, medical schools, and university research institutes. Percentages may not add to 100% because of rounding.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2016) of the Survey of Doctorate Recipients (SDR).

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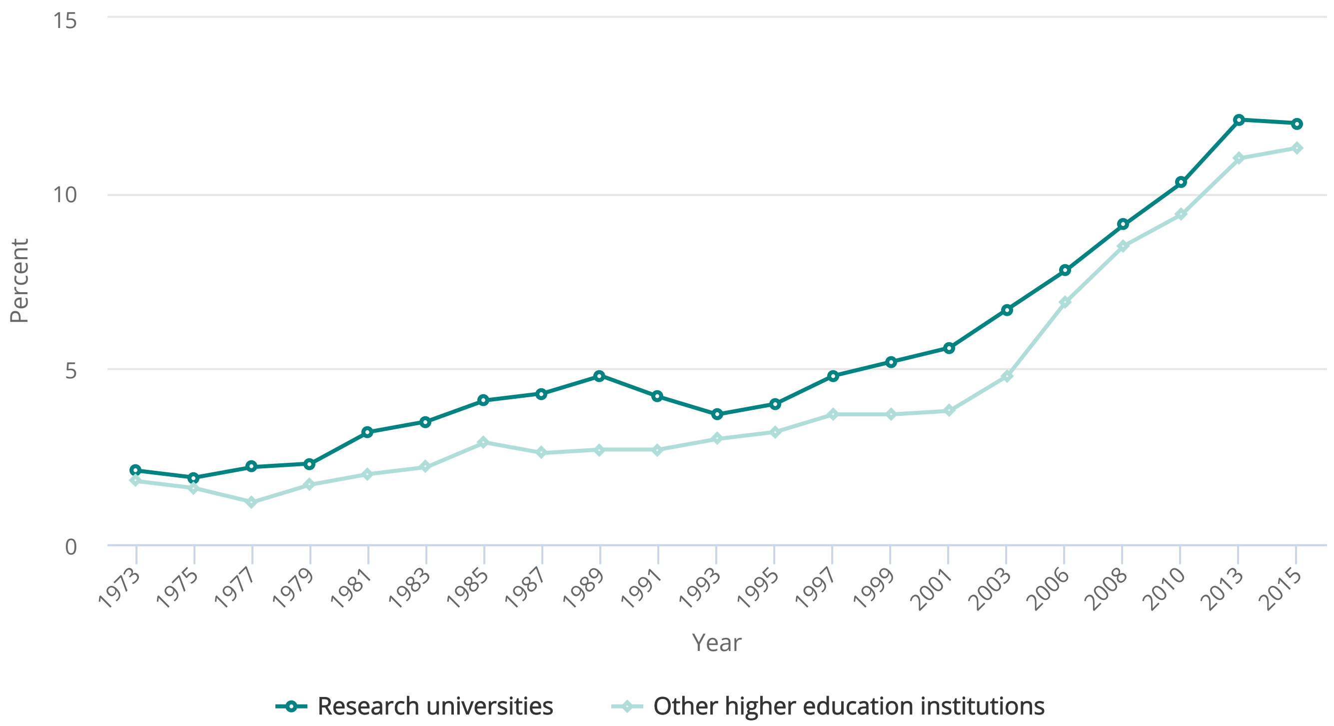
Many of the oldest doctorate full-time faculty work at research-intensive universities, where those ages 60–75 years constituted about 11% of the total in 1995 and about 26% by 2015. Over the same period, there was a decline in the proportion of much younger doctorate holders (ages 30–44 years) employed as full-time faculty at research-intensive universities (from about 42% to about 34%). A comparison of the age distribution of full-time faculty positions at research universities and other universities and colleges shows that there has been a relatively sharp increase at both institution types since the mid-1990s—when ADEA became applicable to the professoriate—in the percentage of these positions held by those ages 65–75 years (Figure 5-17).

FIGURE 5-17

Full-time faculty ages 65–75 at research universities and other higher education institutions: 1973–2015



Note(s)

Academic employment is limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, medical schools, and university research institutes. Faculty positions include full, associate, and assistant professors and instructors from 1973 to 1995; from 1997 to 2015, faculty positions include full, associate, and assistant professors.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Survey of Doctorate Recipients (SDR), and special tabulations (2016) of the 1997–2015 SDR. See Appendix Table 5-18.

Science and Engineering Indicators 2018

Academic Researchers

The interconnectedness of research, teaching, and public service activities in academia makes it difficult to assess the precise size and characteristics of the academic research workforce by examining the employment trends in academic positions. Individuals with the same academic job titles may be involved in research activities to differing degrees or not be involved in research. Therefore, self-reported research involvement is a somewhat better measure than position title for gauging research activity.[13] This section limits the analysis to two groups of academic S&E doctorate holders, including those who reported that research is their primary work activity (i.e., the activity that occupies the most hours of their work time during a typical workweek) and those who reported that research is their primary or secondary work activity (i.e., the activity that occupies the most or second most hours of their work time during a typical workweek). Separate breakouts are provided for all doctorate holders and for full-time faculty. Caution should be exercised in interpreting data about primary work activity because of potential subjectivity in estimating hours devoted to research versus other activities as one's career progresses.[14]

Doctoral S&E Researchers

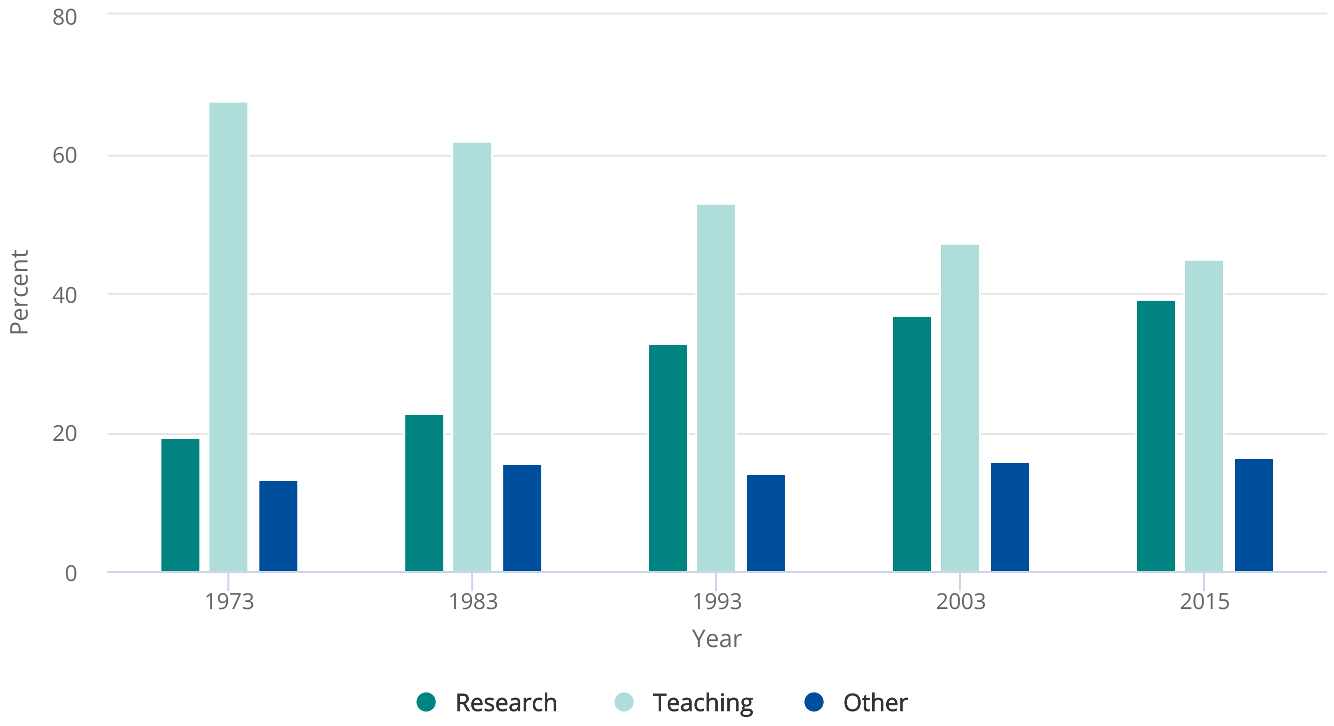
Since 1973, the number of academic researchers (based on primary or secondary work activity) grew from just over 80,000 to more than 220,000 (Appendix Table 5-19). In 2015, of those identified as such researchers, just under 160,000 were employed in full-time faculty positions.[15]

Looking across all doctoral academic positions and across the past four decades, the proportion of researchers has fluctuated between about 60% and 75%. A similar pattern of fluctuation occurred among full-time faculty. In 2015, 67% of S&E doctorate holders in academia and 70% of full-time faculty classified research as their primary or secondary activity.

In 2015, researchers accounted for a larger proportion of the academic doctoral workforce in engineering (77%) than in other fields (between 55% and just under 70%; see Appendix Table 5-19). In physical sciences, life sciences, and psychology, the proportion of researchers declined slightly between the early to mid-1990s and 2015. Turning to the subset who identify research as their primary work activity, somewhat larger shares of doctorate holders reported this in 2015 than in 1993 (41% versus 38%). The same was true for full-time faculty (39% in 2015; 33% in 1993). Looking across the past four decades, the proportion of academically employed S&E doctorate holders who identified research as their primary activity has fluctuated from just below 25% to just over 40%. For full-time faculty, this proportion ranged from just under 20% to just under 40%. Among full-time doctoral S&E faculty, there was a shift in priority from teaching to research from 1973 to 2015, with the proportion of full-time faculty identifying research as their primary work activity climbing from 19% to 39% and the proportion of faculty with teaching as their primary activity falling from 68% to 45% (Figure 5-18).

FIGURE 5-18

Primary work activity of full-time doctoral S&E faculty: Selected years, 1973–2015



Note(s)

Academic employment is limited to U.S. doctorate holders employed full-time at 2- or 4-year colleges or universities, excluding adjuncts and postdoctorates. Full-time faculty includes full, associate, and assistant professors and instructors for 1973, 1983, and 1993; for 2003 and 2015, full-time faculty includes full, associate, and assistant professors. Research includes basic or applied research, development, or design. Other includes a wide range of activities. Percentages may not add to 100% because of rounding.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2016) of the 2015 Survey of Doctorate Recipients (SDR). See Appendix Table 5-18.

Science and Engineering Indicators 2018

The balance of emphasis between teaching and research varied across the disciplines. A higher share of faculty with doctorate degrees in life sciences and engineering identified research as their primary work activity, and a higher share of faculty with doctorate degrees in mathematics and statistics and in social sciences reported teaching as their primary activity. Since the early 1990s, the proportion of doctorate holders who reported research as a primary work activity declined among life scientists from a high base but grew among mathematicians and statisticians, engineers, and social scientists from much lower bases (Appendix Table 5-19).

Career stage plays a role in the reported primacy of research, teaching, or other activities. In 2015, among early- to mid-career doctorate holders—those who had earned their doctorate in 1995 or later—43% reported research as their primary work activity, 40% reported teaching, and the remainder (17%) reported some other activity as primary. Individuals in the older cohort (who earned their doctorate in 1994 or earlier) were slightly more likely to identify teaching as their primary activity (42%) and slightly less likely to report research (36%); they were also more likely to report that their primary activity was neither research nor teaching but some other activity such as management and administration or computer applications (22%).

In 2015, recently degreed S&E doctoral faculty—those who received their doctorate since 2012—were less likely than faculty with a doctorate from 2004 to 2011 to report research as their primary activity. Among those who had earned their degree since 2012, 35% identified research as their primary work activity, a lower proportion than that reported by faculty who had earned their S&E doctorate degree 4–7 years earlier (43%) or 8–11 years earlier (44%) (▦Table 5-18). A similar pattern across career stages prevailed in some, but not all, degree fields.[16]

TABLE 5-18 ▦

Full-time S&E faculty reporting research as primary work activity, by years since doctorate and degree field: 2015

(Percent)

Years since doctorate	All degree fields	Physical sciences	Mathematics and statistics	Computer and information sciences	Life sciences	Psychology	Social sciences	Engineering
All years since doctorate	39.0	38.9	32.1	43.7	43.8	33.1	31.5	47.3
1–3	35.3	16.7	28.6	42.9	30.0	30.0	40.0	40.0
4–7	42.6	41.2	30.0	58.3	40.5	38.2	37.7	57.1
8–11	43.5	46.5	40.9	58.3	44.4	34.2	37.1	53.3
12 or more	37.6	37.7	30.5	36.6	44.7	32.2	28.5	43.6

Note(s)

Academic employment is limited to U.S. doctorate holders employed full-time at 2- or 4-year colleges or universities, medical schools, and university research institutes, excluding adjuncts and postdocs. Faculty includes full, associate, and assistant professors. Research includes basic or applied research, development, and design. Physical sciences include earth, atmospheric, and ocean sciences; life sciences include biological, agricultural, environmental, and health sciences. Caution should be taken in interpreting results because of the small population size for some fields and years.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2017) of the 2015 Survey of Doctorate Recipients (SDR). See Appendix Table 5-19.

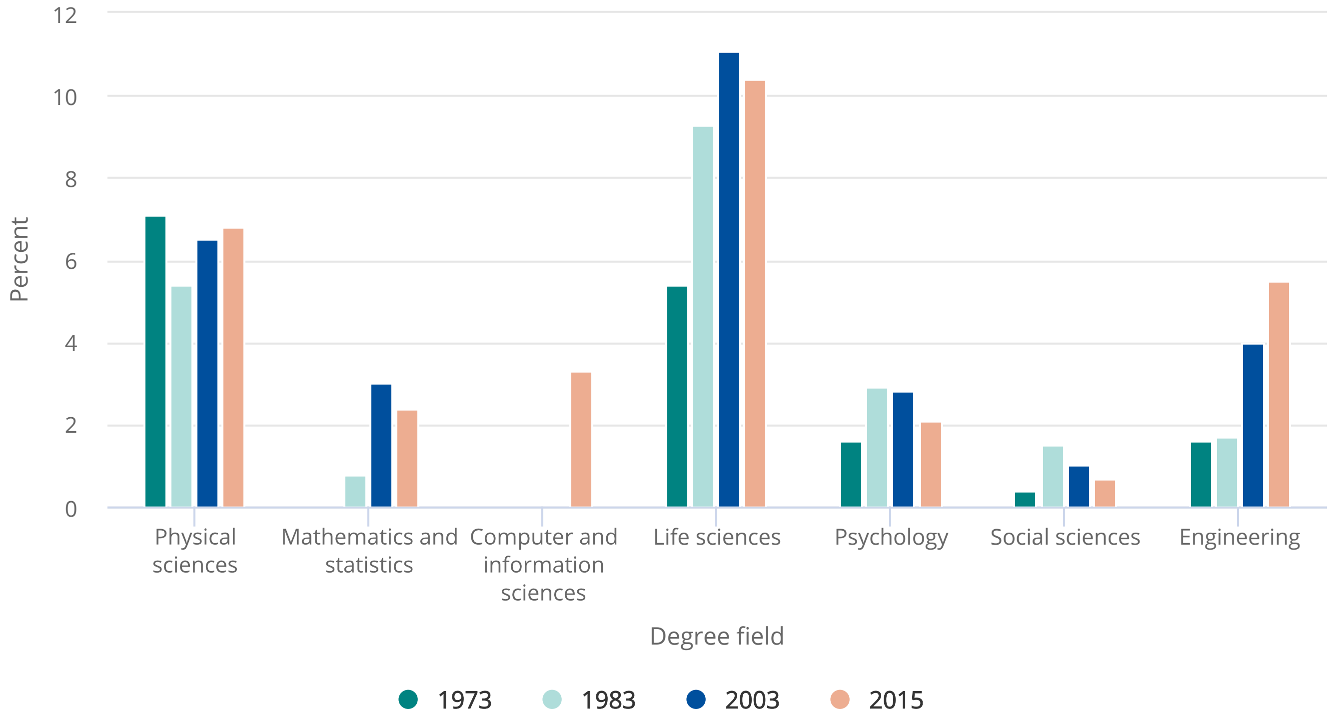
Science and Engineering Indicators 2018

Academic Employment in Postdoc Positions

About 45,000 S&E doctorate holders were employed in academic postdoc positions in 2015 (see sidebar Postdoctoral Researchers).[17] The estimate comes from NSF's Survey of Graduate Students and Postdoctorates in Science and Engineering, which reported a total of about 64,000 postdocs in 2015, with about two-thirds (more than 45,000) holding positions in S&E and almost one-third (just under 19,000) holding positions in clinical medicine or other health-related fields (Arbeit and Kang 2017).[18] The U.S.-trained component of academically employed postdocs with S&E degrees climbed from 4,200 in the early 1970s to 23,300 in 2006 and then declined to 19,200 in 2015 (Appendix Table 5-14). During that time, the proportion of postdocs varied, gradually increasing to just under 9% of all U.S.-trained, academically employed S&E doctorate holders in 2006 and then dropping to just under 6% in 2015. Postdocs were more prevalent in life sciences, physical sciences, and engineering than in social sciences, psychology, mathematics and statistics, and computer and information sciences. Looking over the dozen years from 2003 to 2015, there was growth in the proportion of U.S.-trained postdocs in engineering but not in other fields (Figure 5-19; Appendix Table 5-14). The demographic profile of U.S.-trained individuals employed in academic postdoc positions has changed dramatically over the past 40 years. In particular, the proportions of postdocs held by women, racial and ethnic minorities, and foreign-born individuals have climbed (Table 5-19).

FIGURE 5-19

S&E doctorate holders employed in academia in a postdoctoral position, by S&E degree field: Selected years, 1973–2015



Note(s)

Data for computer sciences are not available for 1973. Data for computer sciences for 2003 are suppressed for reasons of confidentiality and/or reliability. Academic employment is limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, medical schools, and university research institutes, excluding those employed part time who are students or retired. Physical sciences include earth, atmospheric, and ocean sciences; life sciences include biological, agricultural, environmental, and health sciences.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2017) of the 2015 Survey of Doctorate Recipients (SDR).

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TABLE 5-19

S&E doctorate holders employed in academia in postdoc positions, by demographic group: Selected years, 1973–2015

(Percent distribution)

Demographic group	1973	1983	1993	2003	2015
Sex					
Female	16.7	30.1	30.8	37.6	42.7
Male	83.3	69.9	69.2	62.4	57.3
Race or ethnicity					
White	85.7	81.9	68.4	63.1	52.6
Asian or Pacific Islander	11.9	13.3	27.1	30.6	36.5
Underrepresented minority	2.4	4.8	4.5	7.0	8.9
Place of birth					
United States	82.5	81.7	60.9	57.0	49.0
Foreign	17.5	18.3	39.1	43.0	50.5

Note(s)

Academic employment is limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, medical schools, and university research institutes, excluding those employed part time who are students or retired. Underrepresented minorities include blacks or African Americans, Hispanics or Latinos, and American Indians or Alaska Natives. Percentages may not add to 100% because of rounding.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2017) of the 2003 and 2015 Survey of Doctorate Recipients (SDR).

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A temporary postdoc appointment has become a common stop along the career path of S&E doctorate holders, particularly during their early career stages. In 2015, 35% of recently degreed, U.S.-trained S&E doctorate holders in academia were employed in postdoc positions, about the same percentage as those employed in full-time faculty positions (36%) (Appendix Table 5-20). For this discussion, recently degreed individuals are those who received their doctorate within 1–3 years before the 2015 Survey of Doctorate Recipients data collection. Among U.S.-trained, academically employed S&E doctorate holders 4–7 years beyond receipt of their doctoral degree, a smaller proportion (16%) was employed in academic postdoc positions, and 52% held full-time faculty positions (Appendix Table 5-20).

In 2015, more than three-fourths (76%) of recently degreed, U.S.-trained academic postdocs were employed at the most research-intensive universities (Table 5-20).

TABLE 5-20

S&E doctorate holders employed in academia in postdoc positions, by Carnegie classification of employer and years since doctorate: 2015

(Percent distribution)

Institution type	Postdocs (thousands)	Years since doctorate		
		8 or more	4–7	8 or less
All institutions	19.2	100.0	100.0	100.0
Doctorate-granting, very high research	14.1	75.9	74.1	74.7
Other doctorate-granting institutions	1.7	7.2	7.1	8.0
Medical schools and medical centers	2.2	9.6	11.8	11.5
Other universities and colleges	1.2	7.2	5.9	6.3

Note(s)

Academic employment is limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, medical schools, and university research institutes, excluding those employed part time who are students or retired. Institutions are designated by the 2005 Carnegie classification code. For information on these institutional categories, see the Carnegie Classification of Institutions of Higher Education, http://carnegieclassifications.iu.edu/downloads.php, accessed 13 February 2017. Detail may not add to total because of rounding.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2017) of the 2015 Survey of Doctorate Recipients (SDR).

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SIDEBAR

Postdoctoral Researchers

A postdoctorate (postdoc) is a temporary position awarded in academia, industry, government, or a nonprofit organization primarily for gaining additional education and training in research. Ideally, the individual employed in a postdoc position gains these skills under the guidance of an adviser, with the administrative and infrastructural support of a host institution and with the financial support of a funding organization. However, the conditions of postdoc employment vary widely between academic and nonacademic settings, across disciplines, and even within institutions, and formal job titles can be an unreliable guide to actual work roles.

Postdoctoral researchers are important to the S&E enterprise and perform a substantial portion of the nation's research. Most have recently earned their doctoral degree, so they bring new techniques and perspectives that broaden their research teams' experience and make them more competitive in the job market. In addition to conducting research, postdoctoral researchers also educate, train, and supervise students engaged in research; help write grant proposals and papers; and present research results at professional society meetings (COSEPUP 2014).

Federal Research Support of S&E Doctorate Holders Employed in Academia

The federal government provides academic researchers with a substantial portion of overall research support. This support may include assistance in the form of fellowships, traineeships, and research grants. This section presents data for U.S.-trained S&E doctorate holders in academic employment who reported on the presence or absence (but not magnitude or type) of federal support for their work. Comparisons are made over the approximately 40-year period between the early 1970s and 2015 and between the roughly 25-year period between the very early 1990s and 2015.

Academic Scientists and Engineers Who Receive Federal Research Support

The proportion of S&E doctorate holders and researchers in academia who receive federal research support has varied over time, according to reported primacy of research activity and type of academic position held (Appendix Table 5-21). In general, a larger share of doctorate holders and researchers received such support in the late 1980s and very early 1990s than in the early 1970s or in 2015.[19] In 2015, 41% of all U.S.-trained S&E doctorate holders in academia and 52% of those for whom research was a primary or secondary activity reported federal government support.[20] About the same percentage (52%) of those for whom research was a primary or secondary responsibility received federal support in 1973 and 2015. By contrast, the percentage in 1991 was somewhat higher (58%). The fraction of full-time faculty who received federal research support from 1973 to 2015 fluctuated similarly, with a somewhat higher percentage in 1991 (48%) than in 1973 (42%) or in 2015 (40%). By contrast, a larger proportion of academic doctorate holders employed in nonfaculty positions received federal support in 1973 (60%) and in the very early 1990s (59%) than in 2015 (42%).

Federal research support varied by doctoral field. Over the past 40 years, doctorate holders in engineering, physical sciences, and life sciences have been more likely to report receiving federal funding support than their counterparts in mathematics and statistics, psychology, or social sciences (Appendix Table 5-21). The pattern of funding support for individuals with a doctorate in engineering and physical sciences was quite similar overall, with percentages ranging from about 50% in the early 1970s to a peak of about 60% in 1991, followed by an eventual decline to around 53% in 2015. Federal funding for individuals with a doctorate in life sciences, with some dips in 1985 and 1993–97 that reflected changes to the survey question, generally remained around 60% in most years until the last decade, when it began to decline. In 2015, such funding stood at 51%. Federal support for academic R&D in the relatively small field of computer and information sciences has grown from about 35% to 45% since its first measurement in the late 1970s.

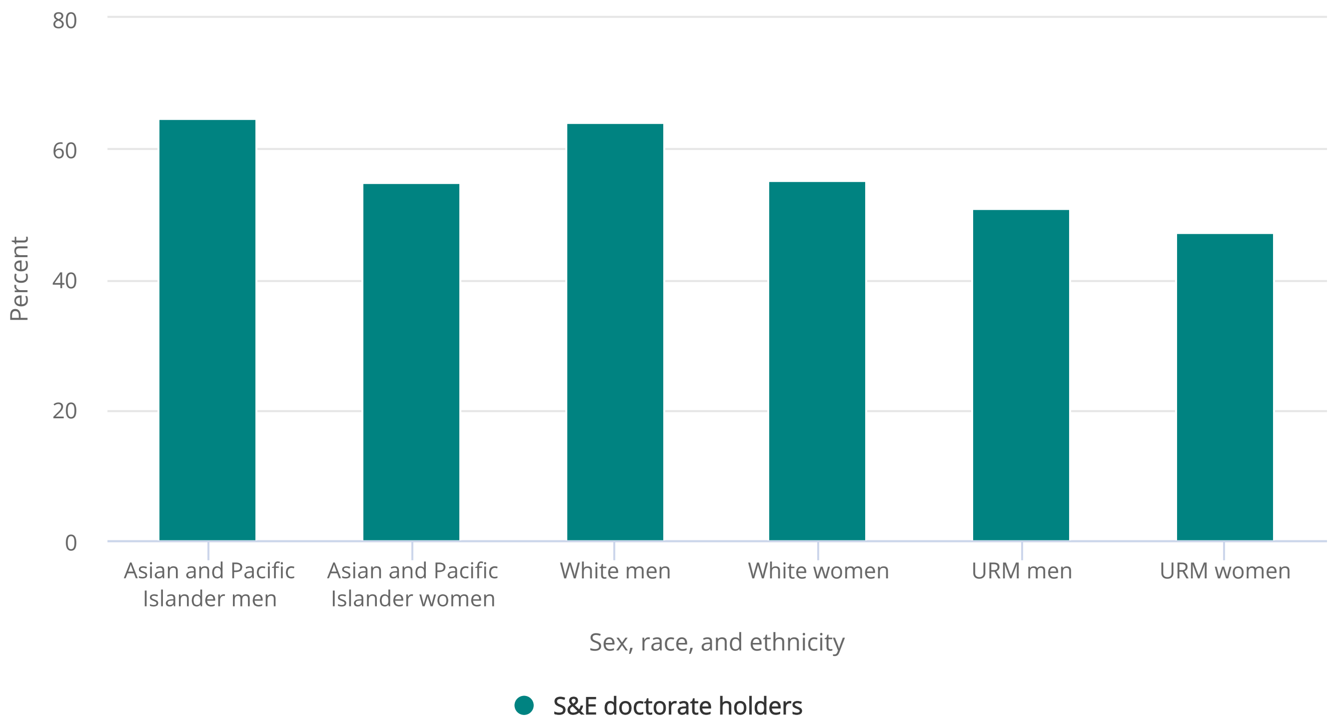
Federal research support is more prevalent in medical schools and in the most research-intensive universities (under Carnegie classification of very high research activity institutions) (Appendix Table 5-22). Just over 60% of S&E doctorate holders employed at the most research-intensive universities received federal support in 2015. At medical schools, about 62% of all doctorate holders and just over 60% of full-time faculty received federal research support in 2015. The percentage with federal support was just over 40% at high research activity institutions; at other universities and colleges, it ranged from about 16% to 33%.

Differences exist by sex, race, and ethnicity in doctorate holders' success in receiving federal research support. Among S&E doctorate holders employed at the nation's most research-intensive universities, white and Asian or Pacific Islander men were more likely than their female counterparts to be supported by federal grants or contracts in 2015 (Figure 5-20; Appendix Table 5-23).

Available data on the rate at which reviewed research grant applications are funded indicate that funding success rates have declined since 2001 at NIH and NSF (Table 5-21). There was an increase during most years in the number of research grant applications that NIH and NSF received.

FIGURE 5-20

S&E doctorate holders employed in very high research activity institutions with federal research support, by sex, race, and ethnicity: 2015



URM = underrepresented minority (black or African American, Hispanic or Latino, and American Indian or Alaska Native).

Note(s)

Academic employment is limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, medical schools, and university research institutes.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Survey of Doctorate Recipients (SDR), 2015. See Appendix Table 5-23.

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TABLE 5-21

NIH and NSF research grant applications and funding success rates: 2001–16

(Number and percent)

Agency	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
NIH																
Proposals	21,967	22,212	24,634	27,461	28,423	29,097	27,325	26,648	26,675	27,850	28,781	29,626	28,044	27,502	28,970	30,106
Awards	6,965	6,799	7,430	6,991	6,463	6,037	6,456	6,116	5,924	6,217	5,380	5,436	4,902	5,163	5,467	6,010
Success rates (%)	32	31	30	26	23	21	24	23	22	22	19	18	17	19	19	20
NSF																
Proposals	23,096	25,241	28,676	31,553	31,574	31,514	33,705	33,643	35,609	42,225	41,840	38,490	39,249	38,882	40,869	41,034
Awards	6,218	6,722	6,846	6,509	6,258	6,708	7,415	6,999	10,011	8,639	7,759	8,061	7,652	7,923	8,993	8,782
Success rates (%)	27	27	24	21	20	21	22	21	28	20	19	21	19	20	22	21

NIH = National Institutes of Health; NSF = National Science Foundation.

Note(s)

Available data vary by agency and are not directly comparable with one another. NIH data shown are for R01-equivalent grants, calculated according to the NIH success rate definition, which counts initial grant applications and resubmitted grant applications received in the same fiscal year as one application (see https://report.nih.gov/success_rates/index.aspx). NIH grant applications exclude grants funded by the American Recovery and Reinvestment Act of 2009 (ARRA). NSF data shown are based on research grant applications received and are counted in the fiscal year in which the award or decline action was taken. NSF data include ARRA grants.

Source(s)

National Institutes of Health, Office of Extramural Research, Office of the Director; National Science Foundation, Office of Budget, Finance, and Award Management.

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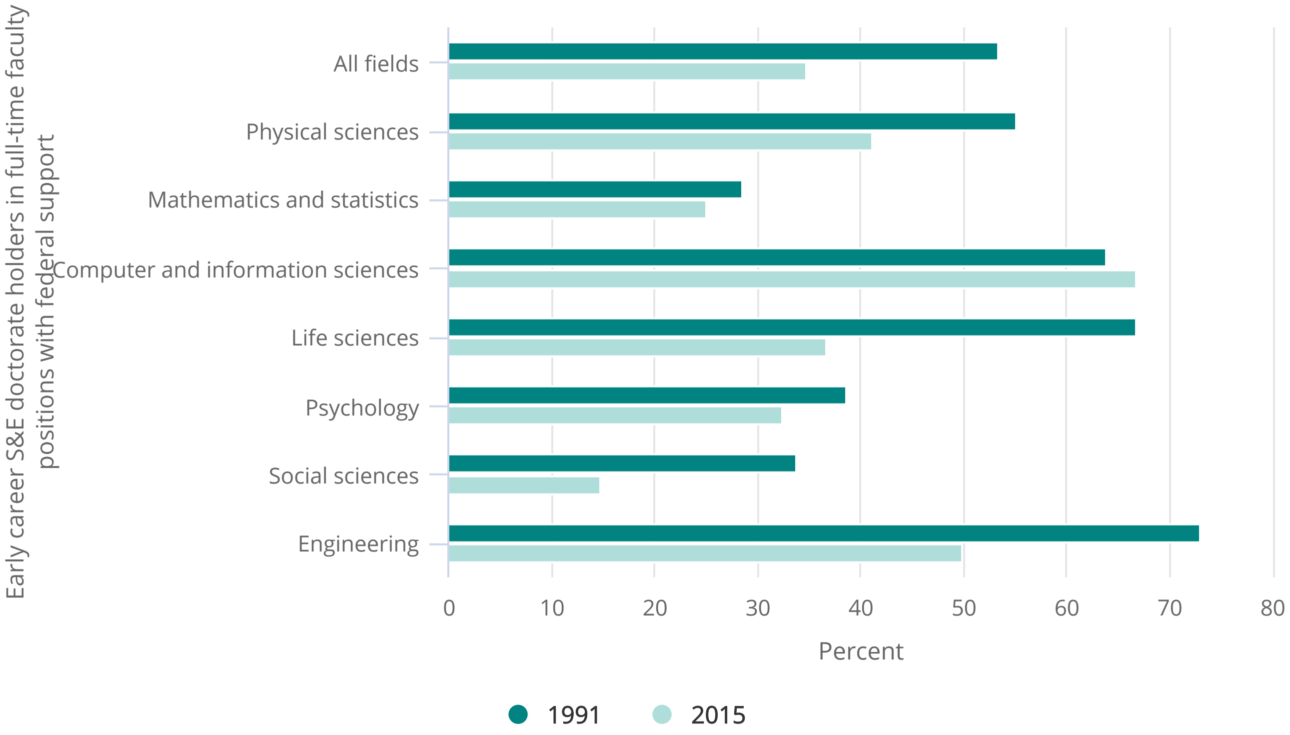
Federal Support of Early Career S&E Doctorate Holders

The very recently degreed S&E doctorate holders—those who earned their doctorates within the previous 1–3 years—have received relatively less federal support in recent years than in past decades. This holds for those in full-time faculty positions (24% in 2015 versus 38% in 1991) and for postdocs (72% in 2015 versus 84% in 1991) (Appendix Table 5-24). In addition, the very recently degreed doctorate holders in full-time faculty positions were less likely to receive federal support than their counterparts who had received their doctorate 4–7 years earlier. This was not the case for those in postdoc positions, however, where similar percentages from each group received federal support.

As with recent doctorate recipients, the proportion of full-time faculty and postdocs 4–7 years beyond their doctorate who received federal support also declined from the early 1990s (Figure 5-21). Looking across the academic doctoral workforce without regard to faculty or postdoc position, the proportion of early career doctorate holders with federal support in 2015 was generally higher in some fields (life sciences, physical sciences, and engineering) than in others (mathematics and statistics, psychology, and social sciences), a long-standing pattern.

FIGURE 5-21

Early career S&E doctorate holders employed in full-time faculty positions with federal support, by field: 1991 and 2015



Note(s)

In this figure, early career faculty are those within 4–7 years of having received their doctorate. Academic employment is limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, medical schools, and university research institutes. See Appendix Table 5-24.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Survey of Doctorate Recipients (SDR).

Science and Engineering Indicators 2018

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[1] For purposes of this discussion, health sciences are combined with biological, agricultural, and environmental life sciences to create the broad field of life sciences.

[2] In the discussion covering the age composition of the academic doctoral workforce, comparisons are made between 1995 and 2015 because the Age Discrimination in Employment Act of 1967 applied to the professoriate starting in 1994. In the section on federal support of doctoral researchers, comparisons are made between 1973, the very early 1990s, and 2015 because of the availability of relatively comparable data for these years.

[3] Among the U.S.- and foreign-trained postdocs overall, there was much greater growth in postdocs from 2000 to 2010 (3.9% average annual growth) than from 2010 to 2015 (0.4% average annual growth).

[4] These other positions included positions at universities and colleges where no tenure system exists and where there are various non-tenure-track positions.

[5] Gaining tenured status has posed particular challenges for doctorate holders employed at medical schools and centers. In 1995, 26% of S&E doctorate holders employed at medical schools and centers (9,600) reported that no tenure system existed for their position; this percentage had increased to 34% by 2015 (17,600). Furthermore, Stephan (2012) notes in *How Economics Shapes Science* that at many medical schools, tenured faculty do not have a commitment for their salary if they do not get grant support; see also Association of American Medical Colleges (2010).

[6] Analysis of trends in minority and underrepresented minority representation in the U.S.-trained academic doctoral workforce is complicated by changes to the Survey of Doctorate Recipients question about race and ethnicity. Specifically, since the early 2000s, respondents have been allowed to report more than one race. Because of this change, data from 2003 to 2015 are not directly comparable with earlier years' data (Milan 2012).

[7] Underrepresented minorities constituted 31% of the U.S. population in 2014, up from 27% in 2004.

[8] Estimates of the percentage of underrepresented minorities by sex in the U.S.-trained academic doctoral workforce are based on small samples and are particularly sensitive to sampling error.

[9] Asians or Pacific Islanders include Native Hawaiians and Other Pacific Islanders. They constituted a small share of the U.S. population in 2004 (4.2%) and 2014 (5.4%).

[10] In 2015, foreign-born individuals constituted 13% of the U.S. population. They were a higher share (29%) of college-educated workers employed in S&E occupations throughout the economy.

[11] In 2015, the majority of postdocs employed in U.S. higher education institutions received their doctorate overseas.

[12] Some academically employed S&E doctorate holders were older than 75 years of age in 1995 and in 2015, but the Survey of Doctorate Recipients does not report on this because it drops respondents from the survey sample after they have reached 75 years of age. Among the overall U.S. population, individuals age 60–75 constituted just under 25% of the population ages 25–75, very similar to their proportion of full-time faculty in higher education.

[13] The Survey of Doctorate Recipients presents respondents with a list of work activities and asks them to identify the activities that occupied the most and second-most hours during their typical workweek. This measure was constructed slightly differently before 1993, and the data are not strictly comparable across the two periods. Before 1993, the survey question asked respondents to select their primary and secondary work activity from a list of activities. Beginning in 1993, respondents were given the same list and asked on which activity they spent the most hours and on which they spent the second-most hours.

[14] Research and teaching are coincident activities in graduate S&E education, and variations in reporting primary (as opposed to secondary) work activities may reflect what is most salient to respondents at different career stages. For example, for early career doctorate holders focused on earning tenure, the activities of running a laboratory and supervising students and postdocs may be more likely to be thought of primarily as research. Later in one's career, as one's focus shifts to facilitating the success of younger colleagues, the same activities may be thought of primarily as teaching.

[15] University-reported data from HERD indicate that approximately 158,000 people paid from R&D salaries and wages were designated as principal investigators in academic FY 2015 and that an additional 745,000 people, including students paid from R&D accounts, were in positions other than principal investigators. Universities reported salaries, wages, and fringe benefits totaling $29.9 billion in FY 2015 for these research personnel.

[16] Caution should be taken in interpreting results because of the small population size for some fields and years since receiving the doctorate as well as the subjectivity involved in estimating primary work activity.

[17] Estimates of postdocs vary according to data source. HERD data report an estimated 66,000 postdocs in 2015 across all S&E and non-S&E fields. Pilot Early Career Doctorates Survey data indicate that about 50,000 S&E postdocs were employed at U.S. academic institutions.

[18] The Survey of Graduate Students and Postdoctorates in Science and Engineering does not include estimates of postdocs employed outside of the academic sector, and comprehensive data are not available on postdocs employed by businesses. See NSF's Survey of Postdocs at Federally Funded Research and Development Centers for data on postdocs at FFRDCs (https://www.nsf.gov/statistics/srvyffrdcpd/) and the Profile of Early Career Doctorates: 2015 (https://nsf.gov/statistics/2017/nsf17313/nsf17313.pdf) for data on individuals within 10 years of having received their doctorate.

[19] Data on federal support of academic researchers for 1985 and 1993–97 cannot be compared with results for the earlier years or with those from 1999 to 2015 because of changes in the survey question. In 1985, the question focused on 1 month and, from 1993 to 1997, on 1 week. In most other survey years, the reference was to the entire preceding year. Because the volume of academic research activity is not uniform over the entire academic year, a 1-week (or 1-month) reference period seriously understates the number of researchers supported at some time during an entire year.

[20] A larger share of the nation's foreign-trained academic doctoral personnel working full time (52%) received federal support in 2015.

Outputs of S&E Research: Publications

The products of academic research include trained personnel and advances in knowledge. Trained personnel are discussed earlier in this chapter and also in Chapter 2. This section presents an indicator of knowledge generated by scientific research: peer-reviewed scientific articles authored worldwide. It also includes data on citations to previously published scientific articles. Chapter 8 (Invention, Knowledge Transfer, and Innovation) provides data on patents, another knowledge-related indicator of scientific output. The content of this section presents the distribution of publications along different dimensions (geography, field, etc.); collaboration across nations, regions, and U.S. sectors; and citation-based measures.

While academic researchers contribute the bulk of all scientific and technical articles published in the United States, the focus in this section is considerably broader. It includes U.S. articles in all sectors and also total U.S. articles in the context of article outputs of the world's nations. The output volume of research, article counts, is one basic indicator of the degree to which different performers contribute to the world's production of research-based S&E knowledge. The outputs of different U.S. sectors—universities and colleges, industry, government, and nonprofit institutions—indicate these organizations' relative prominence in the United States overall and in particular S&E fields. The same indicator, aggregated by country, provides approximate information about the global S&E enterprise and the emergence of centers of S&E activity.

Scientific collaboration in all fields increasingly crosses organizational and national boundaries. Articles with multiple authors in different venues or countries provide an indicator of the degree of collaboration across sectors and nations. Scientific collaboration has risen over the past decade. Cross-sectoral collaboration is viewed as a vehicle for moving research results toward practical application. International collaboration, often compelled by reasons of cost or the issue's scope, provides intellectual cross-fertilization and ready access to work done elsewhere.

Data on citations indicate the perceived usefulness of research results to further advance the state of knowledge. This section will examine both domestic and international citation patterns.

This chapter uses a large database about publications (bibliometric data) whose primary purpose is to provide a searchable database of journals, books, and conference proceedings to the research community. Similar to the old library card catalog, the database provides structured information about written publications such as title, publication and journal information, and author information. The National Center for Science and Engineering Statistics (NCSES) uses the database to examine national and global scientific activity (see sidebar Bibliometric Data and Terminology). Publications enter the database as the structured information become available.

Using the bibliometric data, *Science and Engineering Indicators* produces indicators such as the count of coauthorships in U.S. publications, which is a measure of the collaborations between U.S. researchers and those in other countries. Within the United States, the indicators provide insight on the output of and collaboration between different institutional sectors, including universities, nonprofit research institutes, and government laboratories.

The bibliometric database is tied to the increasingly dynamic world of publications. Historically, the print and online publications were only available to subscribers or for a fee. Increasingly, however, these publications are published or made available online for free, either immediately or after an embargo period (see sidebar Open Access).

SIDEBAR

Open Access

In open access (OA), the author(s) or the publisher of a publication (the rights owner) provides users with free access to use, distribute, transmit, or display the intellectual work. This sidebar summarizes research on the evolving nature of OA, potential impacts to publication models, measurement of OA, and preliminary results assessing the share of U.S. and global publications available in OA.* OA is spreading rapidly as high-speed Internet provides a useful platform for posting and accessing scholarly research.

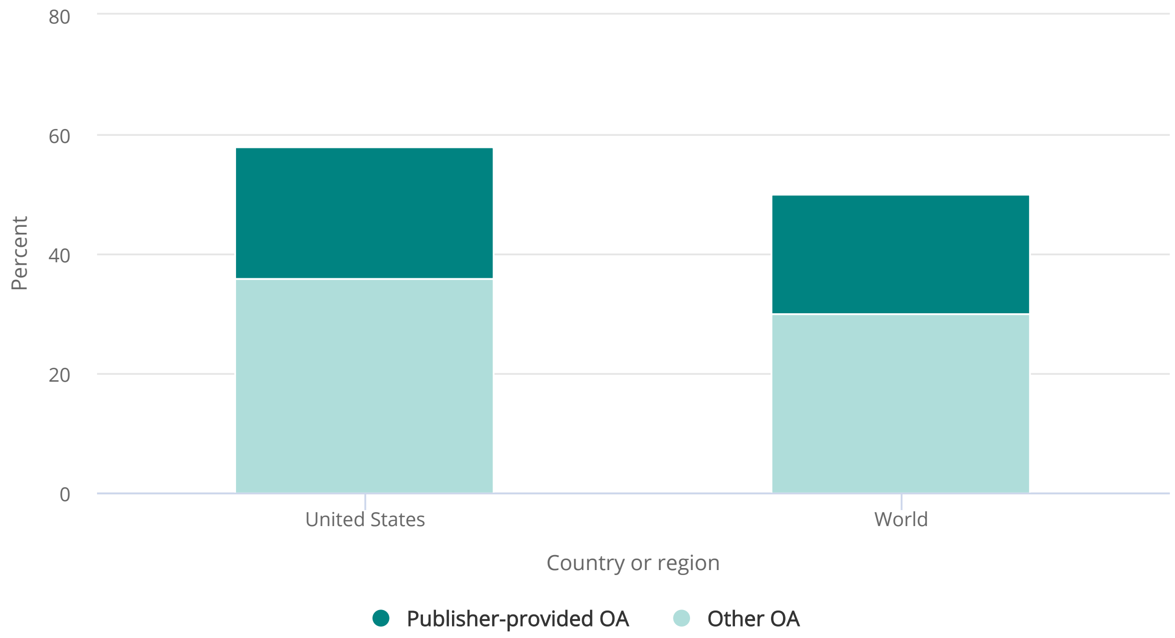
Driving the shift, major research funders and governments increasingly require expanded or free access to the research output they support. For example, in 1998, Brazil established SciELO (Scientific Electronic Library Online) with a goal of improving and expanding dissemination and accessibility of Latin American and Caribbean scientific publications. Since then, 16 other countries in South America, Central America, and Europe have joined. In 2013, the U.S. Office of Science and Technology Policy issued a memorandum, “Increasing Access to the Results of Federally Funded Scientific Research,” prompting the majority of agencies, including NSF, to require investigators to make peer-reviewed journal articles that result from federally funded research publicly available not more than 1 year after their official date of publication.

A recent study by Science-Metrix (Science-Metrix 2017c), corroborated by a European Commission study (Archambault et al. 2014), found that nearly 60% of U.S. publications and about 50% of the publications produced worldwide have become available in OA, as shown in Figure 5-A. This may undercount the true levels of OA, according to Science-Metrix, which performed additional manual validation on a random sample of 1,000 articles. They found the percentage of OA for 2010–14 to be nearly 70% for the United States and just under 60% for the rest of the world.

OA publications are becoming available in a dynamic environment where more material becomes available every day, including new papers coming online shortly or immediately after publication and older papers coming online months after their initial publication following an initial embargo period or as part of a general movement to make older papers freely available. Many venues provide online access to scholarly publications, including publisher and researcher websites, and institutional and subject-specific repositories. As Figure 5-A shows, around the world about 40% of the time publishers provide the OA (often known as “gold OA”), whereas about 60% of the time another source, such as the researcher or his or her institution, provides the access (often known as “green OA”). The green-gold distinction is complicated because although many publications available online are posted legally, some are not. A variety of rights and licensing agreements makes it difficult to assess the legality of postings across the broad diversity of websites.[†]

FIGURE 5-A

Share of publications available in publisher-provided open access and total open access: 2006–15



OA = open access.

Note(s)

Results are computed using full counting. Other OA includes access provided by the researcher or institution and about 15% of OA publications for which the provider was not identified. Total OA shows relative magnitude only.

Source(s)

Science-Metrix; Clarivate Analytics; 1science, accessed November 2016.

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The OA environment challenges the preexisting publication business model, where library and users' subscription fees supported publications and peer review for robustness and originality. In the OA business model, publication costs are often paid by the author or institution. This shift in payment structure challenges researchers to find funds to cover publication fees.

Trends

U.S. OA Publications

As of early 2017, over 50% of U.S. publications from 2006 were available in OA, increasing steadily to over 60% for publication years 2010–14 and then dropping back to 52% for 2015 (Figure 5-B). Lower OA levels for the most recent publication year reflect a common phenomenon of OA: many licensing arrangements contain a provision for an embargo period (often 6–18 months) after initial publication, during which the publisher retains exclusive rights for paid distribution and after which the publications can be distributed more widely for free.

FIGURE 5-B

Annual percentage of U.S. publications available in publisher-provided open access and total open access: 2006–15

OA = open access.

Note(s)

Data are presented according to publication year. Results are computed using full counting. Other OA includes access provided by the researcher or institution and about 15% of OA publications for which the provider was not identified. Total OA shows relative magnitude only.

Source(s)

Science-Metrix; Clarivate Analytics; 1science, accessed November 2016.

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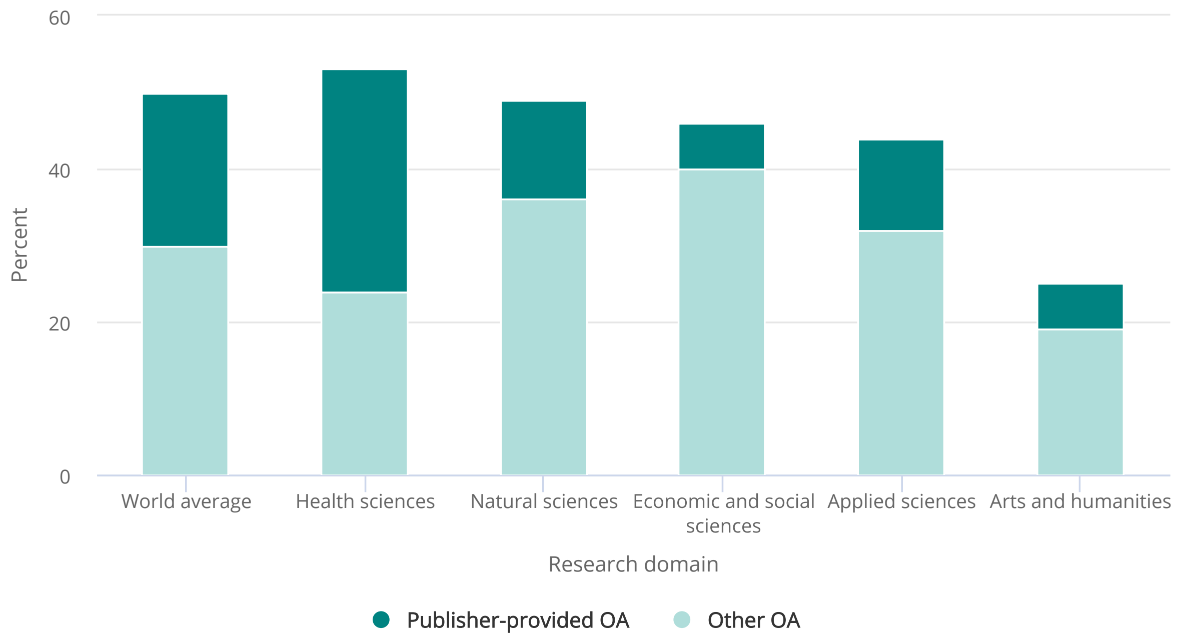
Across Fields

The levels of publisher-provided and total OA vary across research fields (note that the research fields presented in this sidebar are those used in the Web of Science database and are slightly different from those used in other sections of this chapter). The health sciences field has the highest share of OA publications for publisher-provided OA (29%) and total OA (53%) (Figure 5-C). Some 46% of economics and social sciences publications are available in total OA, but only 6% of papers are provided in OA by the publisher specifically. The domain of arts and humanities has the lowest share of publications available in total OA (25%), although the level of publisher-provided OA in this field is similar to levels for economics and social sciences (6%).

The trend toward more and more articles moving to OA is expected to continue as funding organizations increasingly require free access for research results.

FIGURE 5-C

Percentage of publications available in publisher-provided open access and total open access, by research domain: 2006–15



OA = open access.

Note(s)

Data are presented according to publication year. Results are computed using full counting. Other OA includes access provided by the researcher or institution and about 15% of OA publications for which the provider was not identified.

Source(s)

Science-Metrix; Clarivate Analytics; 1science, accessed November 2016.

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* This sidebar reports levels of OA that were assessed by matching the content of a database of OA papers produced by 1science to the Web of Science bibliometric database (produced by Clarivate Analytics; formerly produced by Thomson Reuters).

† For a discussion of the legal complexities, see "Steady, strong growth is expected for open-access journals," *Physics Today,* http://physicstoday.scitation.org/doi/10.1063/PT.3.3550, accessed 30 May 2017.

SIDEBAR

Bibliometric Data and Terminology

Scopus Database. The counts, coauthorships, and citations discussed in the S&E output section are derived from information about research articles, conference papers, reviews, and short surveys (hereafter referred to collectively as “publications”) that are published in peer-reviewed scientific and technical journals, books, and conference proceedings. This information characterizes the publication, the journal, proceedings, or book in which it appears; lists its author(s) and their institutional affiliations; and is collected in Elsevier’s Scopus database. The publications exclude editorials, errata, letters, and other material whose purpose is not to present or discuss scientific data, theories, methods, apparatuses, or experiments. The publications also exclude working papers, which are not generally peer reviewed.*

The publications output database, also known as bibliometric data, undergoes a thorough review and processing to create the data for *Science and Engineering Indicators* (Science-Metrix 2017a). Before National Center for Science and Engineering Statistics (NCSES) analysis, a set of filters was applied to the Scopus database (see sidebar Bibliometric Data Filters). Additionally, for more information about the difference between Scopus and the data used in *Science and Engineering Indicators* before 2016, see sidebar New Data Source for Indicators Expands Global Coverage (NSB 2016). Although the full text of publications in Scopus does not need to be written in English, the publication’s name and the abstract must be available in English for indexing.

Journal Selection. Elsevier selects journals for the Scopus database based on an international group of subject-matter experts, who evaluate candidate journals based on editorial policy, content quality, peer-review policies, peer-review process and capacity, citation by other publications, editor standing, regularity of publication, and content availability.

Book Selection. The books included in the Scopus database are fully referenced and represent original research. They are selected based on publisher characteristics. These include the reputation and impact of the publisher, the size and subject area of the booklist, the publication and editorial policies, the quality of content, and the robustness of peer review.

Conference Selection. Elsevier selects conference materials for the Scopus database by subject field based on quality and relevancy, including the reputations of the sponsoring organization and the publisher of the proceedings.

More information on the selection of journals, books, and conferences is found at https://www.elsevier.com/online-tools/scopus/content-overview and https://www.elsevier.com/solutions/scopus/content/content-policy-and-selection.

Using the Scopus database, NCSES adds additional classifications and creates metrics listed as follows:

Field Classification. NCSES’s WebCASPAR (Integrated Science and Engineering Resources Data System) classifies bibliometric data into the 13 broad fields of S&E. The WebCASPAR taxonomy classifies journals, and each publication is tagged with the field and subfield of the title under which it appears. However, many titles in Scopus are not classified in WebCASPAR; therefore, NCSES extends Scopus by associating these additional publication titles with the WebCASPAR fields with which they have the greatest affinity (methodological details available in http://www.science-metrix.com/sites/default/files/science-metrix/publications/science-metrix_sei_2016_technical_documentation_0.pdf). Appendix Table 5-25 shows data for these fields and their subfields, and Appendix Table 5-26 shows data grouped by regions, countries, or economies.

Publication Counts. Counts are the number of peer-reviewed publications produced by a given region, country, economy, or institutional sector. Publications coauthored by multiple countries or institutional sectors are counted in two ways.

Fractional counting divides the publication count by the proportion of each of the countries or institutional coauthors named on the publication. Fractional counting enables the counts to sum up to the number of total publications (Appendix Table 5-27 through Appendix Table 5-41). *Whole* counting (also called *full* or *integer* counting) assigns one count to each country or institutional sector involved in coauthoring the publication, irrespective of their proportionate involvement in authorship (Appendix Table 5-42 through Appendix Table 5-51). Whereas fractional counting aims to assess the proportionate contributions of countries or sectors, whole counting aims instead to assess the participation of countries or sectors. One result of this difference is that with whole counting, the sum of publications from countries or institutional sectors will exceed the total number of publications. For the United States in 2016, there were 408,985 publications in the Scopus database as measured on a fractional-count basis (Appendix Table 5-41) and 519,289 as measured on a whole-count basis (Appendix Table 5-42).

Average Annual Change. The average annual change (also known as the *compound annual growth rate*) provides a measure of growth over time that accounts for compounding effects year over year. A stable rate of increase year-over-year will lead to exponential growth, and the average annual change reflects what level of annual increase would account for a measured exponential increase. Note that the underlying year-to-year growth may show considerable fluctuation; the average annual change smooths rates that fluctuate over time.

Coauthorship. Coauthorship measures collaboration across countries, regions, economies, and institutional sectors. Publication counts of coauthorship use whole counting, resulting in a full count being assigned to each country or institutional sector contributing to the publication. A publication is considered an international coauthorship when there are institutional addresses for authors from two or more different countries. Appendix Table 5-42 through Appendix Table 5-46 show international coauthorship by field of science.

Index of International Collaboration. Coauthorship or collaboration between countries is more likely between countries with large shares of publication output; thus, international collaboration measures are normalized using each country's total publication output to better reflect the propensity to collaborate. The index of international collaboration assesses each collaboration relationship, accounting for the size of each country's contribution to internationally coauthored publications. The result is a scaled index for country-country pairs, reflecting their tendency to collaborate with each other, relative to their tendency toward international collaboration overall. The measure is indexed to 1.00, meaning that if the pair collaborates more than their international average, the resulting score will be greater than 1.00; if they collaborate less than their international average, it will be less than 1.00.

For example, the United States participated in 38.6% of the world's internationally coauthored publications in 2016. Looking at collaborations specifically between the United States and China, 46.1% of China's internationally coauthored publications in 2016 had a U.S. coauthor. Dividing the actual U.S. share of China's internationally coauthored publications by the U.S. international average overall yields an index value of 1.19. Thus, China coauthors with the United States 19% more often than the pair's international average. The country pair index is always symmetrical, so the United States coauthors with China 19% more often than the pair's international average, just as China collaborates with the United States 19% more often than the pair's international average. Appendix Table 5-44 contains the data for calculating the 2006 and 2016 indices, shown in Appendix Table 5-43. Appendix Table 5-45 shows the U.S. sector publications coauthored with other U.S. sectors and foreign institutions for 2006 and 2016. Appendix Table 5-46 shows the U.S. coauthorship by number of authoring domestic and foreign institutions, by field, for 2003–16.

Sector Coding. NCSES codes each U.S. author's institutional address by economic sector into one of the following six categories: academic, federal government, state or local government, private nonprofit, federally funded research and development centers (FFRDCs), and industry. Additionally, the academic sector was divided into private and public subcomponents. Elsevier itself provides a correspondence table to match some organizations to their sector; other official lists (such as the NCSES Higher Education Research and Development Survey file, the Integrated Postsecondary Education Data System, the Carnegie Classification of Institutions of Higher Education, and the Medicare Hospital Compare data set) have also been cross-referenced. Considerable further coding has been undertaken using a combination of manual and automated approaches. For instance, organizations with "university" or "polytech" in their names have been coded as academic, whereas those with "Inc." or "Corp." in their name have been coded as industry. Manual validation and quality-control measures are also applied to ensure an acceptable level of quality. Given the diversity of U.S. organizations found in the database, sector coding is not exhaustive, and some U.S. organizations remain tagged as unknown (roughly 7%).

Citations and Relative Citation Scores. Citations of S&E publications by other S&E publications provide an indication of the impact of publications and of the flow of knowledge or linkage between sectors or geographic locations. The relative citation (RC) score for each publication adjusts its citation count to its respective year and research subfield, facilitating meaningful comparisons across contexts (Narin and Hamilton 1996; Wang 2012). For instance, average citation counts for 2014 ranged from less than 1 citation per publication in some subfields to more than 15 citations per publication in others. Citation scores presented in *Science and Engineering Indicators 2018* refer to the year in which a publication appears, not the citation year. At least 3 years must elapse after publication before one can reliably assess citation levels (and more years are preferable; see [Wang 2012]), so *Science and Engineering Indicators 2018* presents RC scores for 1996–2014. From 2 to 3 years of citation data are used to compute international citations (Appendix Table 5-47) and the RC index between country pairs (Table 5-28). By contrast, more years of data are used (where available) to compute RC scores elsewhere in this report, noting that normalization of scores by publication year ensures comparability across years, even when publications have not had the same amount of time to collect citations. Because of the need for timely results, citation data for the most recent year (i.e., 2014) are based on individual citation windows ranging from 24 to 36 months, depending on the month in which each publication was released.

Average of Relative Citations. With the relative citation (RC) scores computed, the average of relative citations (ARC) can be computed for each sector or geographic area, offering a view of the average impact within the scientific community, accounting for citation differences over time and across fields of research. The ARC is indexed to 1.00, which represents the world level, meaning that a score greater than 1.00 shows that the entity's publications are cited more than the global average, whereas a score less than 1.00 shows that the entity's publications are cited less than the global average.

The ARC reflects the average impact of a country's total publications. ARC does not account for how many publications each country produces, nor does it measure total influence within the scientific literature. For example, Guinea's ARC of 4.67 compared to the U.S. ARC of 1.42 reflects that the *average* citation level for individual publications is higher for Guinea than it is for the United States. The United States accounts for a larger share of the global citation total than Guinea does, which is unsurprising, given that the U.S. output volume of publications is much larger than that of Guinea.

Science and Engineering Indicators 2018 uses the ARC to assess average impact by region, country, or economy. ARCs are calculated using all data available—noting, once again, that a minimum window of 3 years is imposed—so results are not calculated for publications appearing later than 2014. Figure 5-29 shows changes in the U.S. ARC index by field from 2004 to 2014. Appendix Table 5-49 shows ARCs for U.S. fields of S&E, and Appendix Table 5-50 shows ARCs for regions, countries, or economies.

Highly Cited Publications. Citations to S&E publications are concentrated on a small portion of the total number of cited items. These measures follow a power law, where a relatively small share of the publications gathers a relatively large share of the impact. In these highly skewed distributions, the average is substantially different from the median or "typical" behavior. Thus, average counts alone offer only a partial reflection of the impact of S&E activities, and highly cited publications are shown to round out the assessment. Scores on this indicator are computed as a share of the top percentile of publications based on RC scores, relative to total publication output volume; results are available in Appendix Table 5-48. As noted previously, RC scores are not computed in *Science and Engineering Indicators 2018* for publications appearing after 2014; all available citation data are used to compute scores for the highly cited publications indicator, and results are normalized to the year of publication and the subfield of research.

Measurement Limitations of Bibliometric Data. The Scopus database indexes peer-reviewed S&E publications collected and curated by Elsevier to conform to a set of quality standards, including the stipulation that the abstracts have been written in English. Bibliometric researchers have found an own-language preference in citations (Liang, Rousseau, and Zhong 2012). Thus, the indexing of publications with English-language abstracts can undercount citations associated with non-English publications. This linguistic bias has been found to be more substantial in social sciences than in physical sciences, engineering, and mathematics (Archambault et al. 2009). In addition, contribution levels among authors typically varies, but these differences are not captured in the database.

* For more information, see https://www.elsevier.com/solutions/scopus/content.

The first bibliometrics section, S&E Publication Output, examines the quantity of S&E publications, by national origin and, for the United States, the sectoral origin. The second section, Coauthorship and Collaboration in S&E Literature, investigates the national, international, and U.S. sectoral partnerships producing these publications. The focus is on the country of the institutions, not individual authors. The third section, Trends in Citation of S&E Publications, looks at various patterns of research use across regions, countries, and sectors. All three sections focus on the largest producers of S&E publications and on developed and developing countries, as classified by the International Monetary Fund.[1]

Bibliometric indicators draw on Elsevier's Scopus metadata database of 19,000 journals, 2,700 conference proceedings, and a smaller number of books. For inclusion, journals must have English-language abstracts and titles—this introduces a bias in the data because English is assumed as the global language of science (see sidebar 💬 Bibliometric Data Filters and [Amano, González-Varo, and Sutherland 2016]). In addition, as mentioned earlier, the bibliometric data are administrative data originating from a searchable database of journals, books, and conference proceedings. Administrative data are collected by organizations and government departments for the purpose of registration, transactions, and record keeping. Administrative data are used for social sciences research; the data, however, are not collected using survey or census instruments. As such, the data lack standard statistical database elements, including population-to-sample weighting factors and standard errors.

The output volume of peer-reviewed S&E publications provides insight into the development of scientific and technological capabilities around the globe. These capabilities have risen in China and the developing world, which generally increased their share of total global output from 25% to just under 40% in a decade, even while total global output itself grew (▦ Table 5-22). One-third of the world's gain from 2006 to 2016 reflected growth in the number of articles from China. However, U.S. publications received more citations than China's publications, as shown in the following section.

TABLE 5-22

S&E articles in all fields, by country or economy: 2006 and 2016

(Number and percent)

Rank	Country or economy	Country or economy economic status	2006	2016	Average annual change (%)	2016 world total (%)	2016 cumulative world total (%)
-	World	na	1,567,422	2,295,608	3.9	na	na
1	China	Developing	189,760	426,165	8.4	18.6	18.6
2	United States	Developed	383,115	408,985	0.7	17.8	36.4
3	India	Developing	38,590	110,320	11.1	4.8	41.2
4	Germany	Developed	84,434	103,122	2.0	4.5	45.7
5	United Kingdom	Developed	88,061	97,527	1.0	4.3	50.0
6	Japan	Developed	110,503	96,536	-1.3	4.2	54.2
7	France	Developed	62,448	69,431	1.1	3.0	57.2
8	Italy	Developed	50,159	69,125	3.3	3.0	60.3
9	South Korea	Developed	36,747	63,063	5.5	2.8	63.0
10	Russia	Developing	29,369	59,134	7.2	2.6	65.6
11	Canada	Developed	49,259	57,356	1.5	2.5	68.1
12	Brazil	Developing	28,160	53,607	6.6	2.3	70.4
13	Spain	Developed	39,271	52,821	3.0	2.3	72.7
14	Australia	Developed	33,100	51,068	4.4	2.2	75.0
15	Iran	Developing	10,073	40,974	15.1	1.8	76.7
16	Turkey	Developing	19,547	33,902	5.7	1.5	78.2
17	Poland	Developed	21,267	32,978	4.5	1.4	79.7
18	Netherlands	Developed	24,461	29,949	2.0	1.3	81.0
19	Taiwan	Developed	25,246	27,385	0.8	1.2	82.2
20	Switzerland	Developed	16,385	21,128	2.6	0.9	83.1
21	Malaysia	Developing	3,230	20,332	20.2	0.9	84.0
22	Sweden	Developed	16,634	19,937	1.8	0.9	84.8
23	Belgium	Developed	13,036	16,394	2.3	0.7	85.6

Rank	Country or economy	Country or economy economic status	2006	2016	Average annual change (%)	2016 world total (%)	2016 cumulative world total (%)
24	Czech Republic	Developed	8,839	15,963	6.1	0.7	86.3
25	Mexico	Developing	9,322	14,529	4.5	0.6	86.9
26	Portugal	Developed	7,136	13,773	6.8	0.6	87.5
27	Denmark	Developed	8,536	13,471	4.7	0.6	88.1
28	Austria	Developed	9,155	12,366	3.1	0.5	88.6
29	Israel	Developed	11,040	11,893	0.7	0.5	89.1
30	South Africa	Developing	5,636	11,881	7.7	0.5	89.7
31	Singapore	Developed	8,205	11,254	3.2	0.5	90.1
32	Egypt	Developing	3,958	10,807	10.6	0.5	90.6
33	Norway	Developed	7,093	10,726	4.2	0.5	91.1
34	Greece	Developed	10,684	10,725	0.0	0.5	91.6
35	Finland	Developed	9,204	10,545	1.4	0.5	92.0
36	Romania	Developed	3,523	10,194	11.2	0.4	92.5
37	Thailand	Developing	4,270	9,581	8.4	0.4	92.9
38	Saudi Arabia	Developing	1,898	9,232	17.1	0.4	93.3
39	Pakistan	Developing	2,809	9,181	12.6	0.4	93.7
40	Argentina	Developing	5,600	8,648	4.4	0.4	94.1
41	Indonesia	Developing	619	7,729	28.7	0.3	94.4
42	New Zealand	Developed	5,607	7,465	2.9	0.3	94.7
43	Ukraine	Developing	5,296	7,375	3.4	0.3	95.0
44	Ireland	Developed	4,857	6,834	3.5	0.3	95.3
45	Chile	Developing	3,122	6,746	8.0	0.3	95.6
46	Hungary	Developed	5,530	6,208	1.2	0.3	95.9
47	Colombia	Developing	1,368	6,120	16.2	0.3	96.2
48	Slovakia	Developed	2,644	5,359	7.3	0.2	96.4
49	Tunisia	Developing	1,980	5,266	10.3	0.2	96.6
50	Algeria	Developing	1,288	4,447	13.5	0.2	96.9

na = not applicable.

Note(s)

The countries or economies shown each produced 5,052 publications or more in 2016. The countries or economies are ranked based on the 2016 total. Serbia ranked 50th for 2016 but was removed from the table as growth could not be computed from 2006 since Serbia and Montenegro divided in 2006. Articles are credited on a fractional-count basis (i.e., for articles from multiple countries or economies, each country or economy receives fractional credit on the basis of the proportion of its participating authors). Detail may not add to total because of countries or economies that are not shown. Proportions are based on the world total, excluding unclassified addresses (data not presented). Average annual change, or compound annual growth rate, is $\textit{average growth rate} = (\textit{year 2 publications} / \textit{year 1 publications})^{(1/\textit{number of years})} - 1$. See Appendix Table 5-26 for groupings of regions, countries, or economies. For more information on the International Monetary Fund economic classification of countries, see https://www.imf.org/external/pubs/ft/weo/2016/01/weodata/groups.htm. See Appendix Table 5-27.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; Elsevier, Scopus abstract and citation database, accessed July 2017.

Science and Engineering Indicators 2018

This chapter presents analysis of about 2.3 million peer-reviewed S&E publications from the Scopus database as of July 2017 (Table 5-22). The publication output discussion by geography, field, or institutional level uses fractional counting, which credits coauthored publications according to the collaborating institutions or countries, based on the proportion of their participating authors. As part of our data analysis, we employ filters on the raw Scopus S&E publication data to remove publications with questionable quality (see sidebar Bibliometric Data Filters).

SIDEBAR

Bibliometric Data Filters

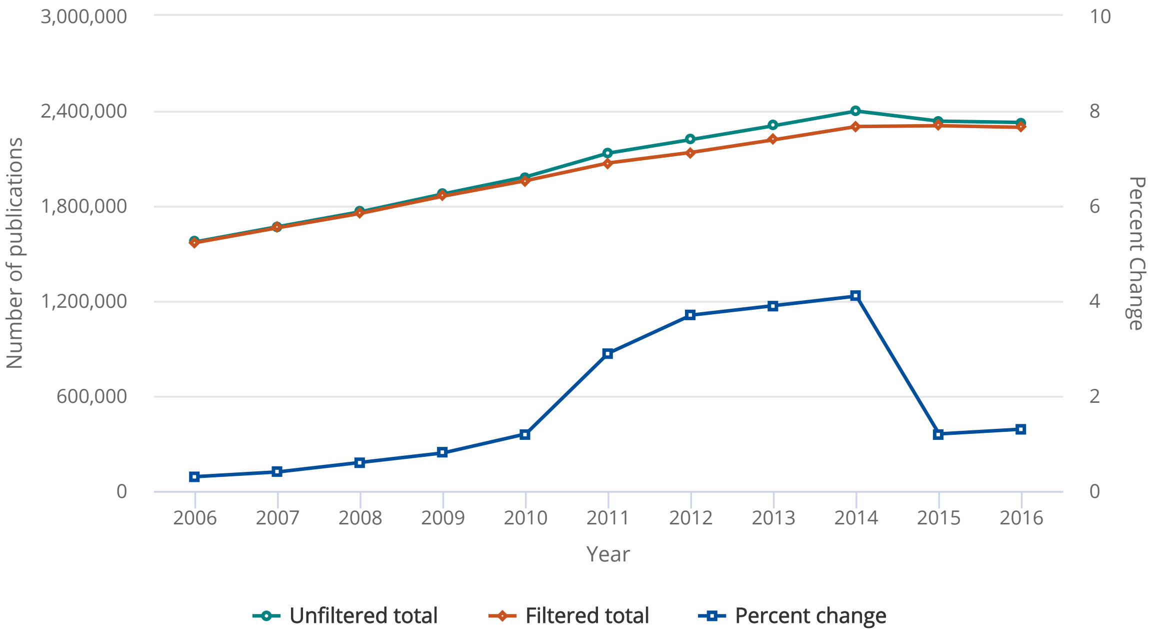
The goal of the bibliometric data analysis presented in this chapter is to measure valid peer-reviewed research output. Recently, bibliometric experts noted an increase of low-quality publications, including journals, conference proceedings, or books lacking substantive peer review.[*] NCSES removed two publication sets from the Scopus database to exclude low-quality publications from the bibliometric data included in this report:

- Journals and proceedings flagged by the Directory of Open Access Journals (DOAJ) for failing to adhere to its list of best practices or being suspected of editorial misconduct.[†]
- Elsevier's list of titles that they removed from the Scopus database from 2014 onward are removed retroactively for the *Indicators* database for all publication years.[‡]

The need for NCSES filtering has increased in recent years. Figure 5-D shows that the number of publications removed was 1% or less for most years, then approached 3% (more than 60,000 publications) in 2011, and grew beyond 3% (81,000–98,000 publications) each year from 2012 to 2014. The number of publications filtered for the *Indicators* database dropped back down to the 1% range in 2015–16 as Elsevier began instituting filters on the Scopus database.

FIGURE 5-D

Filtered and unfiltered publications in Scopus, by year: 2006–16



Note(s)

Percent change is computed as the difference of publications between the filtered and the unfiltered approaches divided by the number of publications in the unfiltered approach.

Source(s)

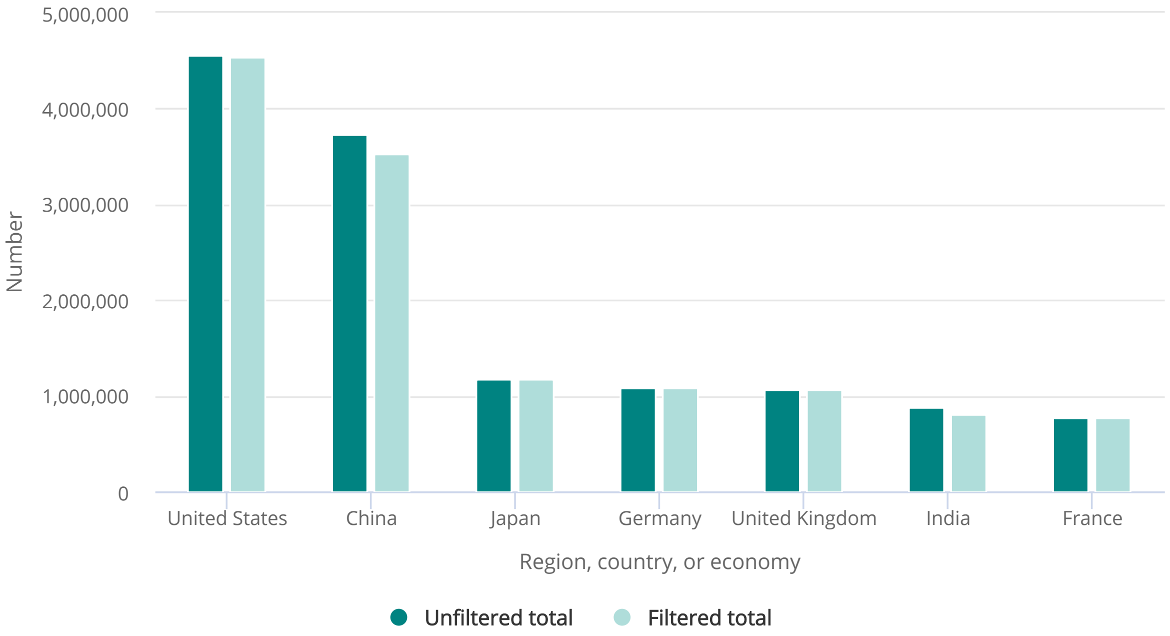
Science-Metrix; Elsevier, Scopus abstract and citation database, accessed July 2017.

Science and Engineering Indicators 2018

Figure 5-E shows the numerical impact of the filters by country or economy. During the last 11 years for which data are available, 2006–16, China saw the most removed publications (more than 215,000 publications removed; approximately 6% of its publication total; more than 50% of all removed publications), followed by India (nearly 62,000 publications removed; 7.6% of its publication total; nearly 14% of all removed publications). Other countries or economies notably affected by this filtering (but not shown in Figure 5-E) include Iran and Malaysia, each had approximately 18,000 publications removed. In the case of Malaysia, this accounted for more than 13% of its total publication output. Beyond these, only Russia and South Korea had more than 8,000 publications removed (about 2% of all publications removed each).

FIGURE 5-E

Filtered and unfiltered publications in Scopus, by region, country, or economy: 2006–16



Source(s)

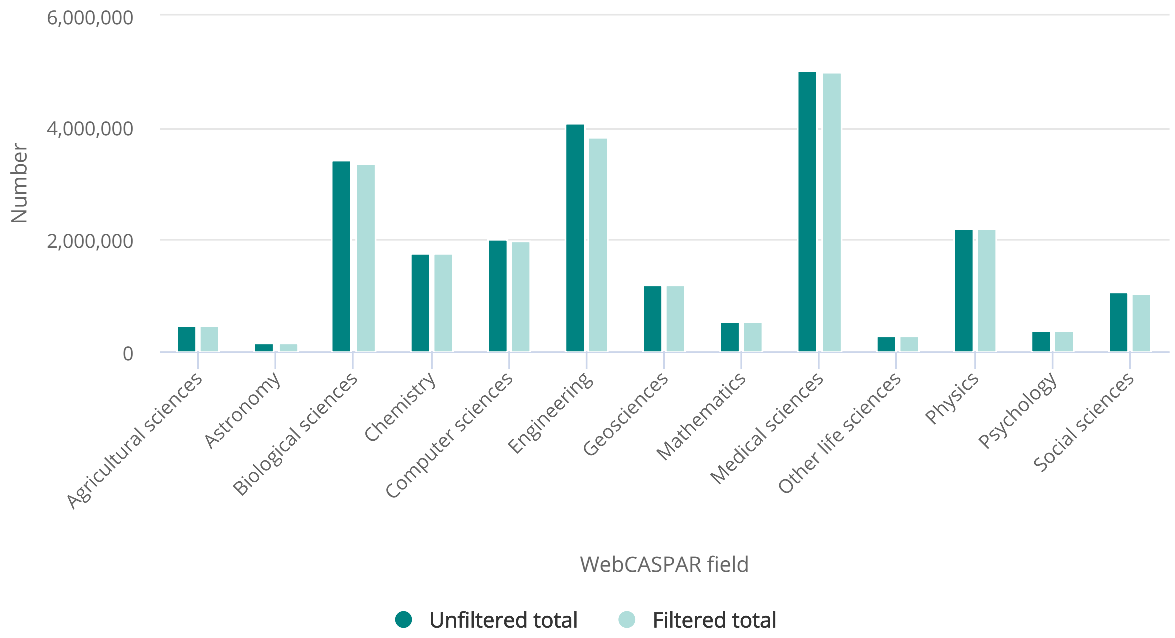
Science-Metrix; Elsevier, Scopus abstract and citation database, accessed July 2017.

Science and Engineering Indicators 2018

The majority of removed publications are conference proceedings. For example, cases where publishers post new conference proceedings every day, each containing many articles, sends a clear red flag concerning robustness, originality, and peer review (Van Noorden 2014). In addition, the biggest filter impact by field is on engineering, where more than 6% of the publications (more than 250,000) were removed in this filtering process (Figure 5-F). This is because conference proceedings comprise both a large share of the removed publications (Table 5-D) and are a large share of the engineering publications.

FIGURE 5-F

Filtered and unfiltered publications in Scopus, by WebCASPAR field: 2006–16



WebCASPAR = Integrated Science and Engineering Resources Data System.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics; Science-Metrix; Elsevier, Scopus abstract and citation database, accessed July 2017.

Science and Engineering Indicators 2018

TABLE 5-D

Number of titles and publications filtered from the Scopus database

(Number)

Filter	Journals		Conference proceedings		Total	
	Titles	Publications	Titles	Publications	Titles	Publications
Scopus	216	162,323	15	238,208	231	400,531
Directory of Open Access Journals	106	67,497	0	0	106	67,497
Total	307	211,595	15	238,208	322	449,803

Note(s)

"Titles" includes journals, books, and conference proceedings, and "Publications" includes the individual items appearing in the titles. Prepared by Science-Metrix using Scopus (Elsevier). Total does not sum to individual sources because there is some overlap between Directory of Open Access Journals and Scopus filters.

Source(s)

Science-Metrix; Elsevier, Scopus abstract and citation database, accessed July 2017.

Science and Engineering Indicators 2018

[*] For an example of journals requiring robust and novel submissions, see https://www.nature.com/authors/policies/peer_review.html. Articles on predatory publication are https://www.nytimes.com/2016/12/29/upshot/fake-academe-looking-much-like-the-real-thing.html?_r=0, https://www.nytimes.com/2013/04/08/health/for-scientists-an-exploding-world-of-pseudo-academia.html, http://science.sciencemag.org/content/342/6154/60.full, and https://www.nature.com/news/predatory-publishers-are-corrupting-open-access-1.11385.

[†] The DOAJ list of excluded journals is available at https://docs.google.com/spreadsheets/d/183mRBRqs2jOyP0qZWXN8dUd02D4vL0Mov_kgYF8HORM/edit. Note that DOAJ also flags serials that are no longer available in open access (OA); although an important and evolving phenomenon in the research landscape, OA status is not associated here with any specific demarcation of quality, whether low or high. Thus, the titles flagged by DOAJ for OA-related reasons alone are not filtered out of the database for *Science and Engineering Indicators 2018*.

[‡] Elsevier's principles of quality can be found at https://www.elsevier.com/solutions/scopus/content/content-policy-and-selection and https://doaj.org/bestpractice. In 2014, during its periodic reevaluation of items flagged for follow-up, the Scopus Content Selection and Advisory Board elected to remove 42 titles as of 2014. The 42 titles are retroactively removed from the *Indicators* database to create a valid time series for bibliometric analysis, even though Elsevier does not claim that these titles were necessarily of low quality before 2014.

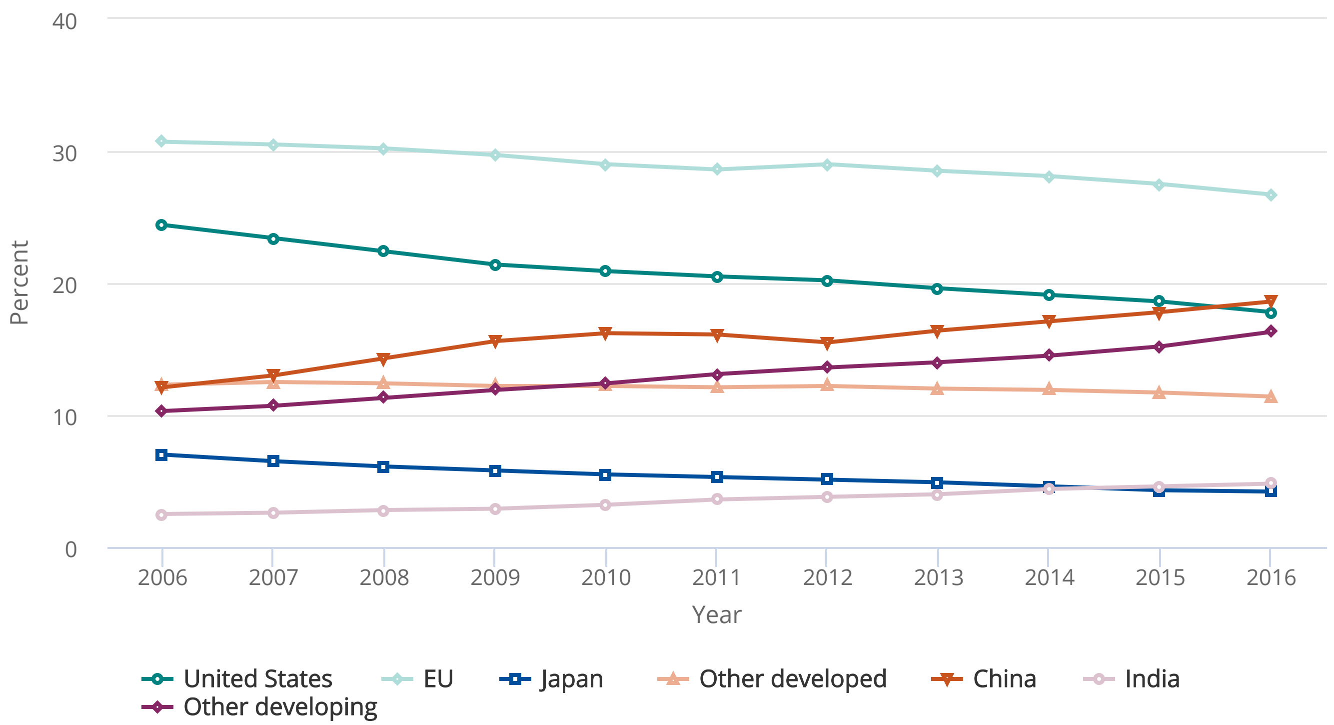
Publication Output, by Country

In 2016, developed economies produced nearly 1.4 million S&E publications, whereas developing economies produced just over 900,000 S&E publications. However, over the last decade, publications from developing economies grew faster than those from developed economies (8.9% versus 1.7%). U.S. S&E publication production grew from just over 383,000 in 2006 to almost 410,000 in 2016, growing merely 0.7% (Appendix Table 5-27). As U.S. publication volume leveled off and developing economies' publication volume grew more rapidly, the U.S. global share fell from 24.4% in 2006 to 17.8% in 2016 (Figure 5-22).

The top five countries producing S&E publications in 2016 are China (18.6% of global output volume), the United States (17.8%), India (4.8%), Germany (4.5%), and the United Kingdom (4.3%). When treated as one entity, the European Union (EU) accounts for 26.7% of the world's S&E publications in 2016 (Table 5-22; Figure 5-22).[2] Although Japan has been a major producer for several decades, Japan's output has trended downward since 2013. In 2016, Japan was the sixth largest global producer of S&E publications. Together, the United States, China, and the EU accounted for almost two-thirds of the world's S&E publications in 2016.

FIGURE 5-22

S&E articles, by global share of selected region, country, or economy: 2006–16



EU = European Union.

Note(s)

Publication counts are from a selection of journals, books, and conference proceedings in S&E from Scopus. Publications are classified by their year of publication and are assigned to a region, country, or economy on the basis of the institutional address(es) listed in the article. Articles are credited on a fractional-count basis (i.e., for articles from multiple regions, countries, or economies, each region, country, or economy receives fractional credit on the basis of the proportion of its participating authors). Some publications have incomplete address information for coauthored publications in the Scopus database and cannot be fully assigned to a region, country, or economy. These unassigned counts, 0.1% of the world total in 2016, are used to calculate this figure but are not shown. See Appendix Table 5-27.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; Elsevier, Scopus abstract and citation database, accessed July 2017.

Science and Engineering Indicators 2018

China has continued its steady growth since the mid-2000s and is now the largest global producer (with an 18.6% global share). India's publication volume has grown rapidly, from 2.5% of global output in 2006 to 4.8% in 2016. Overall, 50 countries —a quarter of those that produced S&E publications in 2016—account for 96.9% of global output.

Between 2006 and 2016, total world S&E publication output grew at an average annual compound rate of 3.9%; the total for developing countries grew more than twice as fast (about 8.6%).[3] China's 8.4% growth rate led the developing countries, resulting in China's collective global share climbing from 12.1% in 2006 to 18.6% in 2016.[4] The strong growth in the developing world points to rapidly increasing science and technology capabilities.

Among other large emerging economies, the 2006–16 average publication growth rate in India was 11.1%; Brazil averaged 6.6%, but this was from a much lower base of total publications. India's and Brazil's 2016 global shares increased to 4.8% and 2.3%, respectively, with India becoming the third largest producer of S&E publications (▦Table 5-22). The change in the absolute number of publications seen during the last 10 years provides context to the growth rate. The absolute increase in the number of publications between 2006 and 2016 is much larger for China (236,406) and India (71,729) than for Brazil (25,447). Rapid growth of S&E publications in Brazil, India, and China coincided with increased R&D expenditures and growth in S&E degrees awarded at the bachelor's- and doctoral-degree levels (see Chapter 2 section International S&E Higher Education). Smaller developing countries with more than 5,000 publications in 2016 and over 15% growth rate from 2006 to 2016 included Iran, Malaysia, Saudi Arabia, Indonesia, and Colombia.

The output of the EU, the world's largest producer, grew 2.5% from 2006 to 2016, faster than the average for developed countries (1.7%). Among EU member countries, growth rates were lower for the three largest producers—France (1.1%), Germany (2.0%), and the United Kingdom (1.0%)—and were generally much higher in smaller member countries. Several former Eastern Bloc countries, including the Czech Republic, Romania, and Slovakia, had publication growth rates above 6.0% for 2006–16. Like that of the United States, the EU's global share fell, from 30.7% in 2006 to 26.7% in 2016.

In Japan, absolute numbers of S&E publication output declined at a 1.3% average rate over 2006–16, decreasing Japan's global share from 7.0% to 4.2% during this period. Publication output from other developed economies outside of the EU and the United States grew, particularly in Australia, Norway, South Korea, and Singapore.

The distribution of S&E publication output by field indicates the priorities of scientific research in different locations. The S&E publication portfolios of five major producers—the United States, the EU, China, Japan, and India—have distinct differences by field (▦Table 5-23; Appendix Table 5-28 through Appendix Table 5-40). Nearly half of U.S. publications are focused on biological sciences, medical sciences, or other life sciences, compared with 38.6% for the world at large in 2016. The United States also produces a higher proportion of S&E publications than the rest of the world in psychology and social sciences. In this context, it is useful to acknowledge that publications in the Scopus database must have an abstract in the English language to be included in the publication counts (Archambault et al. 2009), meaning that publication counts in the social sciences, where publications are more likely in the national language, may be underestimated where English is not the country's national language.

TABLE 5-23

S&E research portfolios of selected region, country, or economy, by field: 2016

(Percent)

Field	World	United States	EU	China	Japan	India
All articles (number)	2,295,608	408,985	613,774	426,165	96,536	110,320
Engineering	18.4	12.3	14.6	28.9	17.1	24.2
Astronomy	0.6	0.8	0.9	0.3	0.5	0.4
Chemistry	7.9	5.1	6.7	12.3	9.1	10.1
Physics	8.7	6.7	8.3	9.9	12.4	9.0
Geosciences	5.7	5.0	5.5	7.1	3.8	4.9
Mathematics	2.3	2.0	2.6	2.0	1.7	1.9
Computer sciences	8.3	6.4	8.6	8.7	8.1	14.1
Agricultural sciences	2.2	1.2	2.0	2.2	1.5	2.6
Biological sciences	15.3	17.9	15.0	14.0	15.2	14.5
Medical sciences	22.1	29.3	24.4	13.3	27.9	15.3
Other life sciences	1.2	2.4	1.3	0.2	0.4	0.4
Psychology	1.7	3.5	2.1	0.3	0.6	0.2
Social sciences	5.3	7.2	8.0	1.0	1.5	2.4

EU = European Union.

Note(s)

Article counts are from a selection of journals in S&E from Scopus. Articles are classified by their year of publication and are assigned to a region, country, or economy on the basis of the institutional address(es) listed in the article. Articles are credited on a fractional-count basis. See Appendix Table 5-26 for regions, countries, and economies included in the EU. Percentages may not add to 100% because of rounding.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; Elsevier, Scopus abstract and citation database, accessed July 2017. See Appendix Table 5-28 through Appendix Table 5-40.

Science and Engineering Indicators 2018

Like the United States, the EU is more focused on biological sciences, medical sciences, and other life sciences; these three fields together account for 40.7% of the EU's publications, compared with the 38.6% of world publications. Relative to the United States, the EU has higher shares of publications in physics, chemistry, and engineering. Relative to the world total, China's S&E publications are more heavily focused on engineering, chemistry, physics, and geosciences. Engineering publications made up 28.9%, and chemistry publications made up another 12.3%, of China's publication output in 2016.

Engineering publications as a share of total publication output volume for India in 2016 (24.2%) are also above the world proportion (18.4%). India's portfolio has the highest concentration in computer sciences of the regions, countries, and economies discussed here, with a 14.1% share, and is above world average concentration in chemistry.

Recent bibliometric research has focused on merging administrative data sets to explore publication data by gender, potentially revealing differences between countries and research fields (see sidebar S&E Publication Patterns, by Gender).

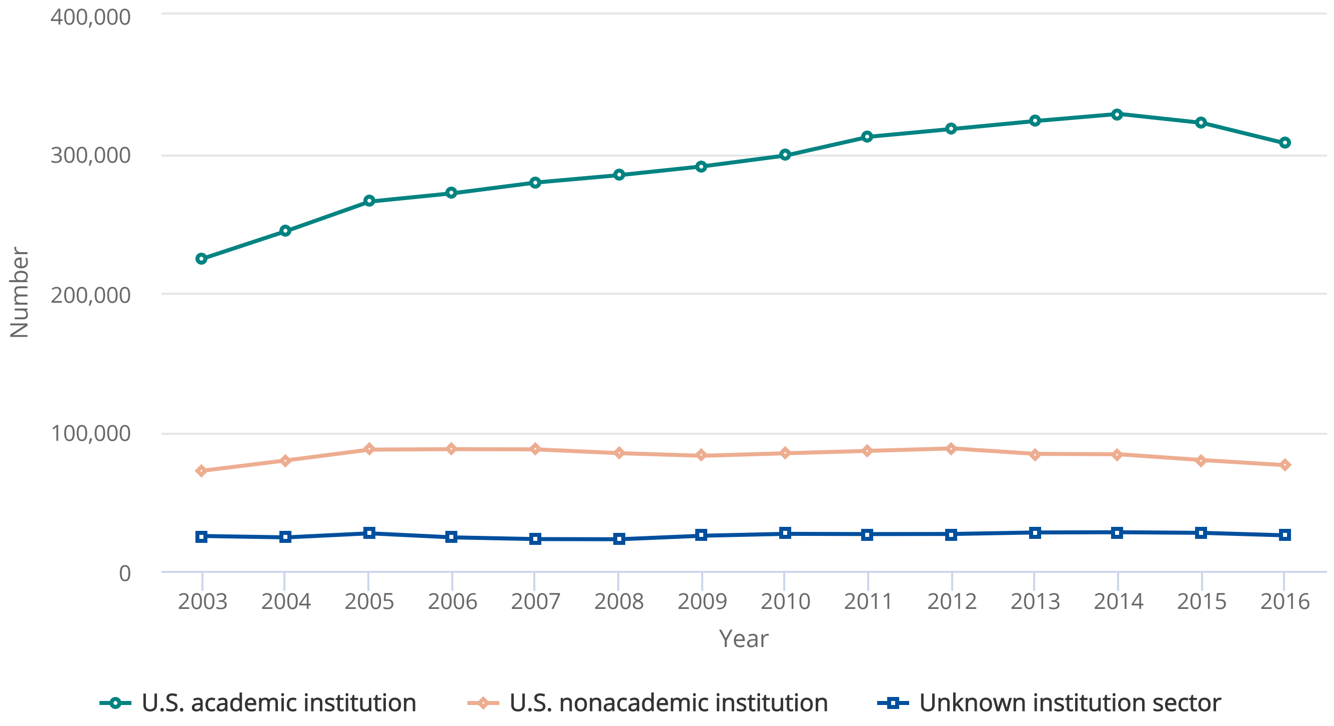
Publication Output, by U.S. Sector

This report divides the U.S. institutional landscape into six sectors, each of which produced S&E publications: the federal government, industry, academia, federally funded research and development centers (FFRDCs), private nonprofit organizations, and state and local governments.[5]

In the United States, the academic sector is the largest producer of S&E publications, accounting for three-fourths of U.S. S&E publication output. This sector was largely responsible for the growth of U.S. S&E publication output between 2006 and 2016. The number of academic S&E publications increased from 271,502 to 307,413 between these years, rising from 70.9% to 75.2% as a share of all U.S. publications (📊Figure 5-23). Public universities accounted for 44.2% of all U.S. publications, and private universities accounted for 25.3% (Appendix Table 5-41).

FIGURE 5-23

U.S. academic and nonacademic S&E articles: 2003–16



Note(s)

Articles refer to publications from a selection of journals, books, and conference proceedings in S&E from Scopus. Articles are classified by their year of publication and are assigned to fields of science by matching the journal in Scopus to the National Science Foundation's subfields (Appendix Table 5-25). Articles are credited on a fractional-count basis (i.e., for articles from multiple regions, countries, and economies, each region, country, or economy receives fractional credit on the basis of the proportion of its participating authors). See Appendix Table 5-41.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; Elsevier, Scopus abstract and citation database, accessed July 2017.

Science and Engineering Indicators 2018

S&E publications in U.S. non-academic institutions fell from 87,513 in 2006 to 76,012 in 2016. Trends in non-academic sectors include the following (Appendix Table 5-41):

- Industry publications reached a high of 33,498 in 2005 and then declined to 24,565, or 6.0% of the U.S. total, in 2016.
- Federal government publications grew in the early 2000s, peaking at 22,580 in 2012 and declining to 19,556 in 2016, accounting for 4.8% of the U.S. total in 2016.
- Publications from FFRDCs grew to a peak of 10,927 in 2012 and have declined to 9,107 in 2016.

- Publications with institutional addresses in the private nonprofit sector decreased slightly (from 21,555 in 2006 to 21,248 in 2016), accounting for 5.2% of U.S. publications in 2016.

As noted previously, life sciences (biological sciences, medical sciences, and other life sciences) dominate the research portfolios of U.S. sectors, accounting for nearly half or more of all publications produced in the federal government, academic, private nonprofit, and state and local government sectors (Appendix Table 5-41). The dominance of life sciences is especially pronounced in the nonprofit sector, with 86.9% of publications in these fields: 63.1% in medical sciences, 19.8% in biological sciences, and 4.1% in other life sciences. With a much larger number of total publications, academia has 49.2% of its S&E literature in life sciences. The exception to the life sciences focus is the research portfolio of industry (28.2% engineering) and FFRDCs (29.6% physics); most of the FFRDCs are controlled by DOE or DOD.[6] The largest science fields in the FFRDC portfolio are physics (within physical sciences) (29.6%), chemistry (14.1%), and engineering (24.6%).

TABLE 5-24

Share of U.S. S&E articles, by sector and field: 2016

(Percent)

Sector	Federal government	Industry	Academic	FFRDCs	Private nonprofit	State and local government	Unknown institutional sector
All fields combined (number)	19,556	24,565	307,413	9,107	21,248	1,537	25,560
Agricultural sciences	3.0	0.8	1.3	0.2	0.2	1.2	1.2
Astronomy	1.6	0.3	0.8	2.6	0.4	0.1	0.4
Biological sciences	26.2	14.2	18.1	7.7	19.8	26.7	14.5
Chemistry	3.7	7.3	5.3	14.1	1.1	0.9	2.7
Computer sciences	2.9	11.3	6.7	5.8	1.0	0.6	6.1
Engineering	13.1	28.2	11.2	24.6	1.9	4.8	13.4
Geosciences	10.1	7.0	4.4	9.2	2.2	17.0	6.5
Mathematics	0.8	0.9	2.5	0.9	0.3	0.1	1.0
Medical sciences	24.5	14.8	28.8	4.5	63.1	38.8	32.8
Other life sciences	1.3	1.7	2.3	0.1	4.1	3.7	5.0
Physics	8.4	11.3	6.2	29.6	0.9	0.5	4.7
Psychology	1.4	0.7	4.1	0.1	1.6	1.9	3.4
Social sciences	2.9	1.5	8.3	0.6	3.4	3.6	8.5

FFRDC = federally funded research and development center.

Note(s)

Articles refer to publications from a selection of journals, books, and conference proceedings in S&E from Scopus. Articles are classified by their year of publication and are assigned to fields of science by matching the journal in Scopus to the National Science Foundation's subfields (Appendix Table 5-25). Articles are credited on a fractional-count basis (i.e., for articles from multiple countries, economies, or sectors, each country, economy, or sector receives fractional credit on the basis of the proportion of its participating authors). The sum of sectors may not add to the field total because of rounding.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; Elsevier, Scopus abstract and citation database, accessed July 2017. See Appendix Table 5-41.

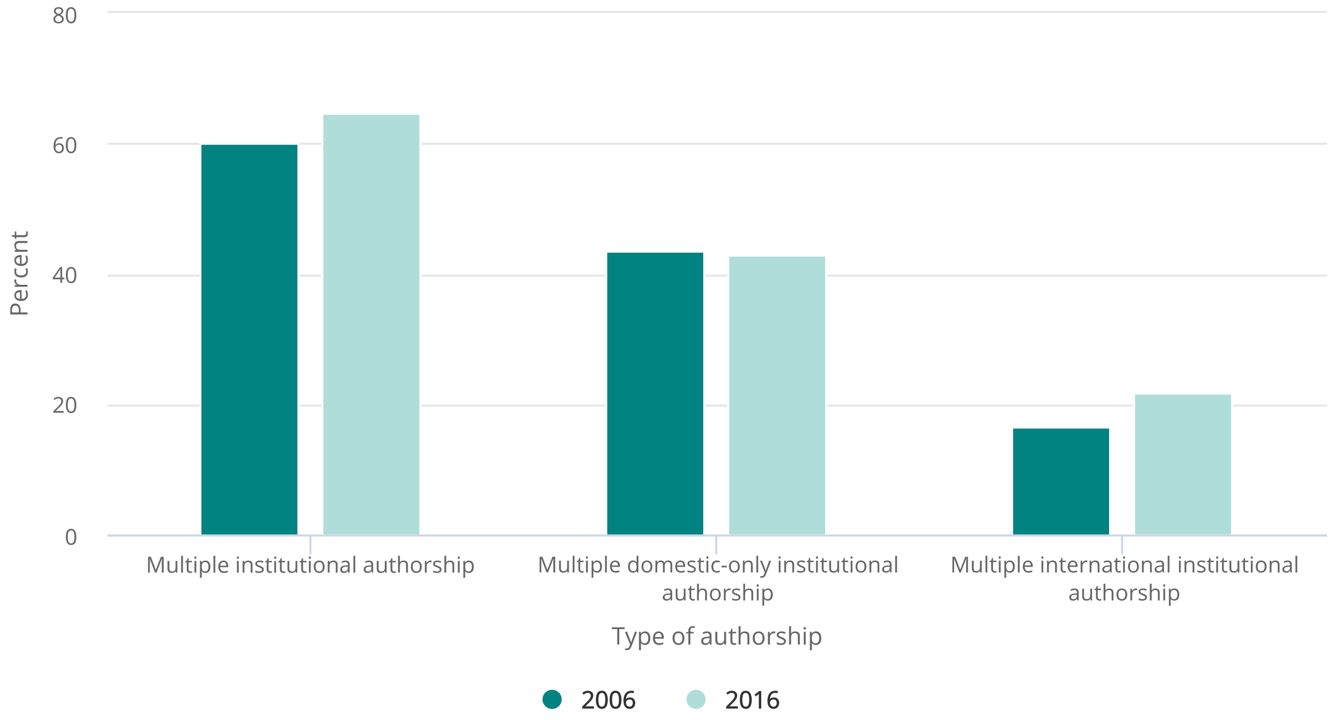
Science and Engineering Indicators 2018

Coauthorship and Collaboration in S&E Literature

Coauthorship on S&E research publications is based on multiple institutional addresses associated with the same publication. Such interconnections among researchers in different institutional settings may indicate researchers' growing capacity to address complex problems by drawing on diverse skills and perspectives. Collaborative S&E research facilitates knowledge transfer and sharing among individuals, institutions, and nations. Between 2006 and 2016, international collaboration increased; domestic-only collaboration held steady as a share of the total, and single-institution authorship declined (📊Figure 5-24).

FIGURE 5-24

Share of world articles in all fields with authors from multiple institutions, domestic-only institutions, and international coauthorship: 2006 and 2016



Note(s)

Article counts refer to publications from a selection of journals, books, and conference proceedings in S&E from Scopus. Articles are classified by their year of publication and are assigned to a region, country, or economy on the basis of the institutional address(es) listed in the article. Articles are credited on a whole-count basis (i.e., each collaborating region, country, or economy is credited with one count). Articles with multiple institutions are counts of articles with two or more institutional addresses. Articles with multiple domestic institutions only are counts of articles with more than one institutional address within a single region, country, or economy. Articles with international institutions are counts of articles with institutional addresses from more than one country or economy. See Appendix Table 5-42.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; Elsevier, Scopus abstract and citation database, accessed July 2017.

Science and Engineering Indicators 2018

Collaboration among U.S. Sectors

U.S. coauthorship data at the sector level—academic, nonprofit, industry, FFRDCs, and federal and state government—indicate collaboration among U.S. sectors and between U.S. sectors and foreign institutions. Over the period 2006–16, the share of publications produced in collaboration with other U.S. sectors or with foreign institutions increased in all sectors

(▦ Table 5-25).[7] The proportion of academic publications coauthored with other U.S. sectors and foreign institutions increased from 41.4% in 2006 to 51.0% in 2016. The share of academic publications coauthored with foreign institutions increased from 24.9% to 37.2% over this period. FFRDCs, where the research conducted focuses primarily on the physical sciences, have the highest percentage of international coauthorship of U.S. sectors, at 45.6% in 2016.

TABLE 5-25

Shares of U.S. sector publications coauthored with other U.S. sectors and foreign institutions: 2006 and 2016

(Percent)

Year	U.S. sector					
	Academic	Federal government	Industry	FFRDCs	Private nonprofit	State and local government
2006						
All publications (number)	355,041	43,086	57,340	19,414	46,395	3,954
Total coauthored	71.4	84.9	75.8	77.1	87.9	90.0
Total coauthored with another U.S. sector or foreign institution	41.4	74.9	64.5	71.7	75.9	81.2
Coauthored with another U.S. sector	21.1	65.3	51.6	57.6	64.7	77.4
Coauthored with academic sector	na	54.4	42.4	49.5	57.1	63.8
Coauthored with nonacademic sector	21.1	25.8	20.2	19.7	20.8	37.4
Coauthored with foreign institutions	24.9	24.0	22.5	33.3	24.1	14.0
2016						
All publications (number)	437,682	45,214	50,889	20,650	50,146	4,298
Total coauthored	76.0	88.6	81.5	86.6	89.2	91.7
Total coauthored with another U.S. sector or foreign institution	51.0	81.9	73.2	82.5	81.3	87.2
Coauthored with another U.S. sector	20.4	71.0	55.7	66.2	70.6	83.6
Coauthored with academic sector	na	63.5	49.1	60.8	66.7	74.0
Coauthored with nonacademic sector	20.4	25.8	19.4	18.8	18.5	37.2
Coauthored with foreign institutions	37.2	33.5	34.9	45.6	32.9	19.1

na = not applicable.

FFRDC = federally funded research and development center.

Note(s)

Article counts are from a selection of journals, books, and conference proceedings in S&E from Scopus. Articles are classified by their year of publication and are assigned to a sector on the basis of the institutional address(es) listed in the article. Articles are credited on a whole-count basis (i.e., each collaborating institution type is credited one count in each qualifying group). The sum of articles coauthored with various sectors could exceed the total number of articles coauthored with another sector or foreign sector because of articles coauthored by multiple sectors. Counts of publications coauthored with another U.S. sector are limited to copublications involving the U.S. sector at stake and another different sector. For instance, the number of coauthored publications with the nonacademic sectors for FFRDCs does not include publications coauthored by two FFRDCs. Articles from unknown U.S. sectors are not shown. See Appendix Table 5-45.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; Elsevier, Scopus abstract and citation database, accessed July 2017.

Science and Engineering Indicators 2018

International Collaboration

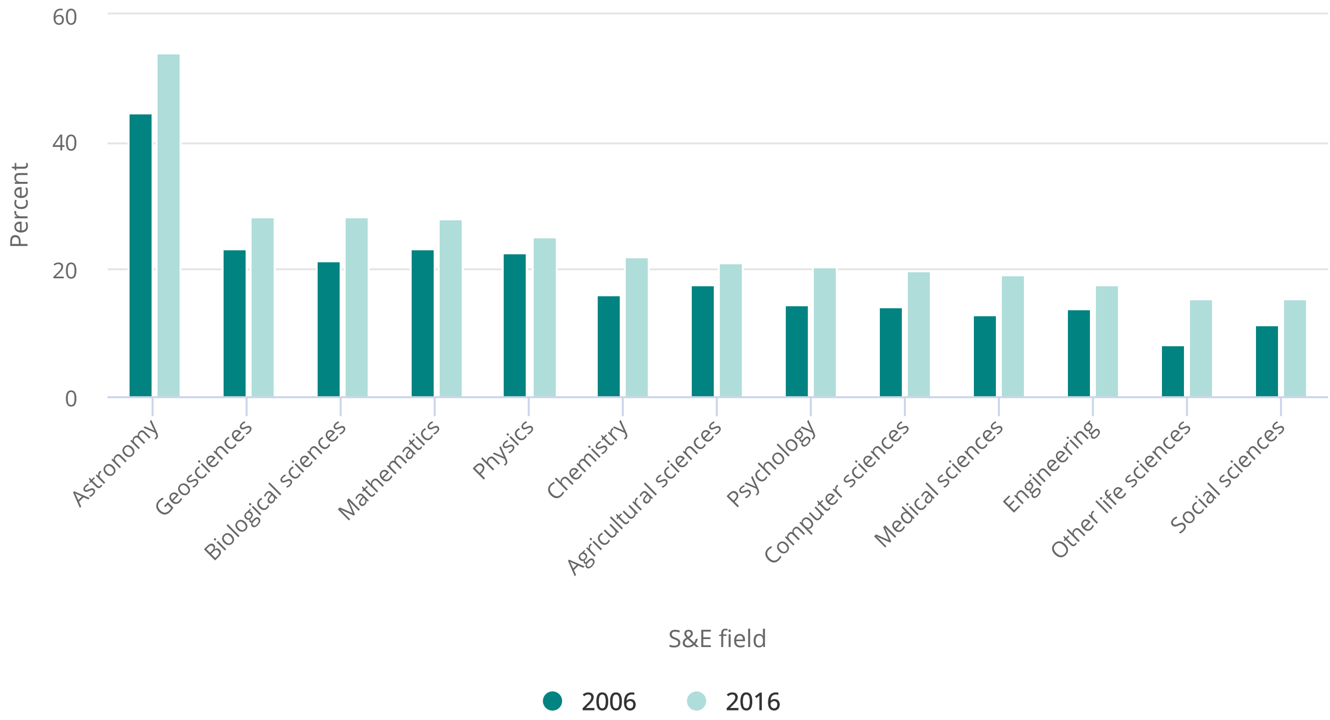
The percentage of worldwide publications produced with international collaboration—that is, by authors with institutional addresses from at least two countries—rose from 16.7% to 21.7% between 2006 and 2016 (Figure 5-24). This increase in part reflects increasing global capabilities in R&D and an expanding pool of trained researchers, as well as improvements in communications technology. These collaborations may also reflect the strengthening of a network of international scholars who increasingly collaborate with each other (Wagner, Park, and Leydesdorff 2015). Finally, the research challenges of climate change, food, water, and energy security are fundamentally global, rather than national, in scope, thereby calling for international research collaboration (Royal Society 2011). Although these factors affect the overall trend, the patterns of international scientific collaboration also reflect wider relationships among countries, including linguistic and historical factors, as well as geographic, economic, and cultural relations (Glänzel and Schubert 2005; Narin, Stevens, and Whitlow 1991).

Percentages of international collaboration, by field

The increase in international coauthorship occurs in every broad field of science. Astronomy is the most international field, with more than half of its publications internationally coauthored (54.0%) in 2016 (Figure 5-25). Geosciences, mathematics, biological sciences, and physics also have percentages of international collaboration above the average of 24.2% across all fields. Factors influencing variations among fields include the existence of formal international collaborative programs and the use of costly research equipment (e.g., atomic colliders, telescopes), which result in cost sharing and collaboration among countries. However, even fields with relatively low percentages of international collaboration have experienced increases in collaboration between 2006 and 2016. For example, over the time period, social sciences grew from 11.4% to 15.4%, and engineering grew from 13.7% to 17.7%.

FIGURE 5-25

Share of world S&E articles with international collaboration, by S&E field: 2006 and 2016



Note(s)

Articles refer to publications from a selection of journals, books, and conference proceedings in S&E from Scopus. Articles are classified by their year of publication and are assigned to a region, country, or economy on the basis of the institutional address(es) listed in the article. Articles with international collaboration are counts of articles with institutional addresses from more than one country or economy. Articles are credited on a whole-count basis (i.e., each collaborating region, country, or economy is credited with one count).

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; Elsevier, Scopus abstract and citation database, accessed July 2017.

Science and Engineering Indicators 2018

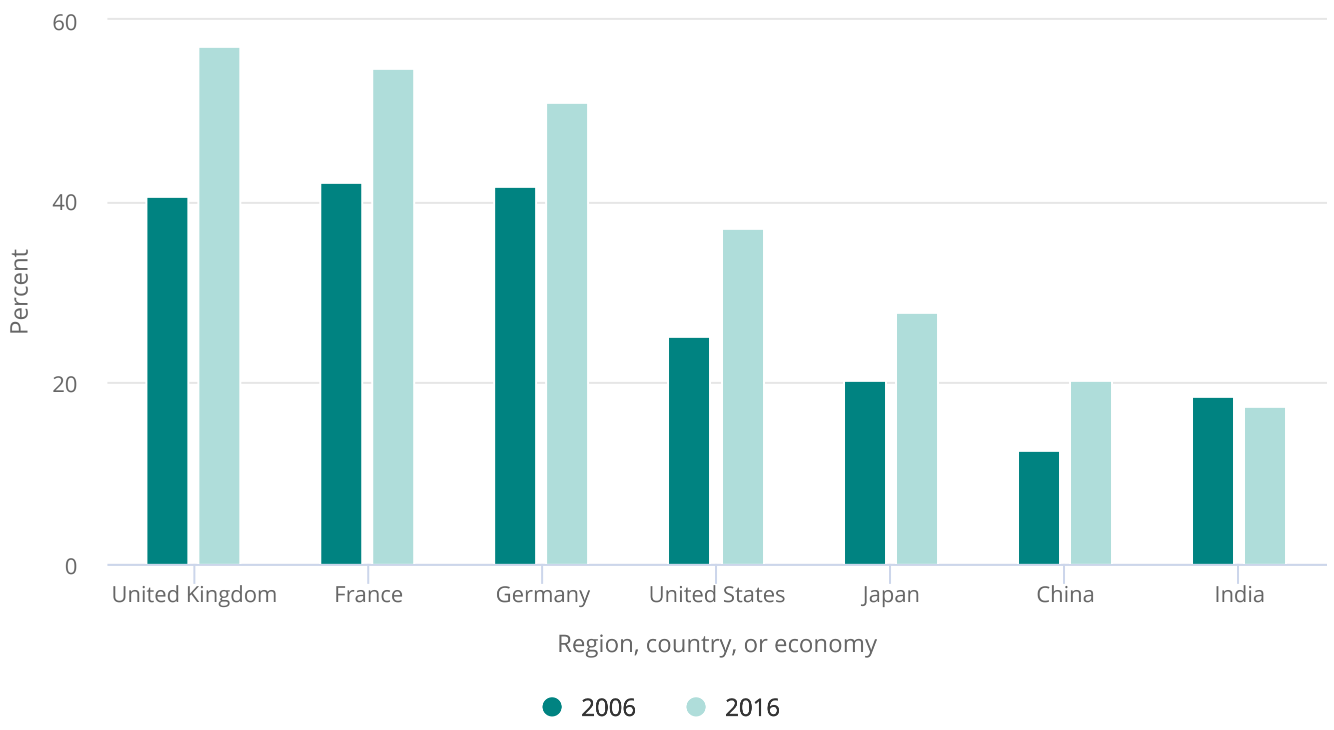
International collaboration, by region, country, or economy

Countries vary widely in the proportion of their internationally coauthored S&E publications. Scale effects play a role in this. Countries with large populations or communities of researchers may have high rates of domestic coauthorship because of the large pool of potential domestic coauthors in their field. Researchers in smaller countries have a lower chance of finding a potential partner within national borders, so collaborators are more likely beyond their national borders. The EU program Horizon 2020 (like its predecessor, the 7th Framework Programme for Research and Technological Development) actively promotes and funds international collaboration within the EU.[8]

The aforementioned publication output data in Figure 5-22 show the 28 nations of the EU as one region.[9] By individual country, Figure 5-26 shows the percentages of international collaboration for the largest producers of S&E publications in 2016. The nations within this group that had the highest percentages of international collaboration in 2016 were three EU nations, the United Kingdom, France, and Germany, which are also the three largest European producers of S&E publications. International collaboration increased for these European countries between 2006 and 2016.

FIGURE 5-26

Share of S&E articles internationally coauthored, by selected region, country, or economy: 2006 and 2016



Note(s)

Articles refer to publications from a selection of journals, books, and conference proceedings in S&E from Scopus. Articles are classified by their year of publication and are assigned to a region, country, or economy on the basis of the institutional address(es) listed in the article. Articles are credited on a whole-count basis (i.e., each collaborating country or economy is credited with one count). Articles with international institutions are counts of articles with institutional addresses from more than one country or economy. See Appendix Table 5-42.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; Elsevier, Scopus abstract and citation database, accessed July 2017.

Science and Engineering Indicators 2018

China increased its collaboration percentage across the same period but was slightly below the world average for 2016 (21.7%). The share of Indian publications that are coauthored with another country declined from 18.5% in 2006 to 17.4% in 2016.

Collaboration partnerships

This section describes global partnership patterns, with special focus on patterns of U.S. involvement in international collaboration.

U.S. institutional authors collaborate most frequently with authors from China, currently the largest producer of S&E publications. China accounted for 22.9% of U.S. internationally coauthored publications in 2016 (Table 5-26). Other substantial partners for the United States include the United Kingdom (13.4%), Germany (11.2%), and Canada (10.2%).

China, South Korea, and Canada are notable among these countries for having unusually high percentages of U.S. participation in their own internationally coauthored publications (46.1%, 47.6%, and 43.5%, respectively). For the other 12 countries in Table 5-26, the shares range from 25.3% to 36.1%.

TABLE 5-26

International coauthorship of S&E articles with the United States, by selected country or economy: 2016

(Percent)

Country or economy	U.S. share of country's or economy's international articles	Country's or economy's share of U.S. international articles
World	38.6	na
China	46.1	22.9
United Kingdom	29.5	13.4
Germany	28.5	11.2
Canada	43.5	10.2
France	25.3	7.5
Italy	28.5	6.6
Australia	28.8	6.3
Japan	32.7	5.4
South Korea	47.6	5.0
Spain	25.0	5.0
Netherlands	29.8	4.7
Switzerland	31.4	4.4
Brazil	36.1	4.0
India	32.0	3.5
Sweden	28.7	3.3

na = not applicable

Note(s)

Articles refer to publications from a selection of journals, books, and conference proceedings in S&E from Scopus. Articles are classified by their year of publication and are assigned to a country or economy on the basis of the institutional address(es) listed in the article. Articles are credited on a whole-count basis (i.e., each collaborating country or economy is credited with one count). Articles with international institutions are counts of articles with institutional addresses from more than one country or economy. See Appendix Table 5-44.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; Elsevier, Scopus abstract and citation database, accessed July 2017.

Science and Engineering Indicators 2018

A measure of the relative strength of collaborative ties between two countries can be obtained by dividing a country's share of collaboration with a specific country by its overall share of international collaborations. This index is 1.00 (unity) when coauthorship between two countries is exactly proportional to their overall shares of international collaborations (▦ Table 5-27). Index values above 1.0 indicate stronger ties, while scores below 1.0 indicate weaker collaborative ties (see sidebar 💬 Bibliometric Data and Terminology).

Geographical regional collaboration, as measured by this index of international collaboration, shows trends that reflect geographic proximity and other historical factors (▦ Table 5-27; Appendix Table 5-43 and Appendix Table 5-44). In North America, the Canada-U.S. index shows a percentage of collaboration that is 13% (1.13) greater than would be expected by size of overall international collaboration alone and that has not changed much between 2006 and 2016.

TABLE 5-27

Index of international collaboration on S&E articles, by selected country or economy pair: 2006 and 2016

(International collaboration index)

Country or economy pair	2006	2016
North and South America		
Canada–United States	1.14	1.13
Mexico–United States	0.98	1.04
Mexico–Argentina	2.89	4.64
Mexico–Chile	2.38	4.09
Argentina–Brazil	4.76	4.78
Argentina–Chile	8.15	8.31
Europe		
France–Germany	0.87	1.16
France–UK	0.82	1.01
UK–Ireland	2.04	2.16
Belgium–Netherlands	2.81	3.09
Poland–Czech Republic	3.37	5.07
Hungary–Romania	5.09	10.55
Spain–Portugal	2.97	3.43
Scandinavia		
Finland–Sweden	3.97	4.15
Finland–Norway	3.31	3.79
Sweden–Denmark	3.62	3.65
Middle East		
Saudi Arabia–Egypt	40.65	13.69
Turkey–Iran	1.63	3.26
Turkey–Israel	1.02	2.08
Asia and South Pacific		

Country or economy pair	2006	2016
China–Japan	1.51	1.09
South Korea–Japan	1.88	1.83
Australia–Malaysia	1.37	1.54
Australia–China	1.08	1.15
Australia–New Zealand	3.72	3.38
India–South Korea	1.48	2.16

UK = United Kingdom.

Note(s)

The international collaboration index shows the first country's rate of collaboration with the second country, divided by the second country's rate of international coauthorship. Articles are credited on a whole-count basis (i.e., each collaborating country or economy is credited with one count). Articles with international institutions are counts of articles with institutional addresses from more than one country or economy. See Appendix Table 5-43.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; Elsevier, Scopus abstract and citation database, accessed July 2017.

Science and Engineering Indicators 2018

Proximity alone does not explain these relationships. Language may be a factor. The U.S.-Mexico index is relatively stable and is just what would be expected by overall shares of international coauthorship alone—near unity. Mexico has very strong collaboration with the Spanish-speaking South American nations of Argentina and Chile (4.64 and 4.09, respectively, for 2016). In turn, Argentina is likely to collaborate with regional neighbors Brazil and Chile. Collaboration between the United Kingdom and Ireland is more than twice what would be expected: 2.16 in 2016.

In addition to the above-average relationships that reflect geographic proximity, Appendix Table 5-43 shows other strong collaboration relationships that reflect historical, linguistic, and educational ties between nations. For example, Spain had a collaboration index measure in 2016 that was two to three times higher than expected with Mexico, Argentina, and Chile. Despite the substantial geographic distances, the United Kingdom has a higher-than-expected collaboration index with Australia and New Zealand. Malaysia has higher-than-expected collaboration ties with the Middle East nations Iran and Saudi Arabia in 2016.

Strong collaboration relationships also evolve over time among countries with strong educational ties, such as the United States and China, where the collaboration index has increased from 0.88 to 1.19 from 2006 to 2016. China is the largest foreign country of origin for international recipients of U.S. S&E doctorates. China accounted for more than one-quarter of all international S&E doctorate recipients from 1995 to 2015 (see Chapter 2 section International S&E Doctorate Recipients).

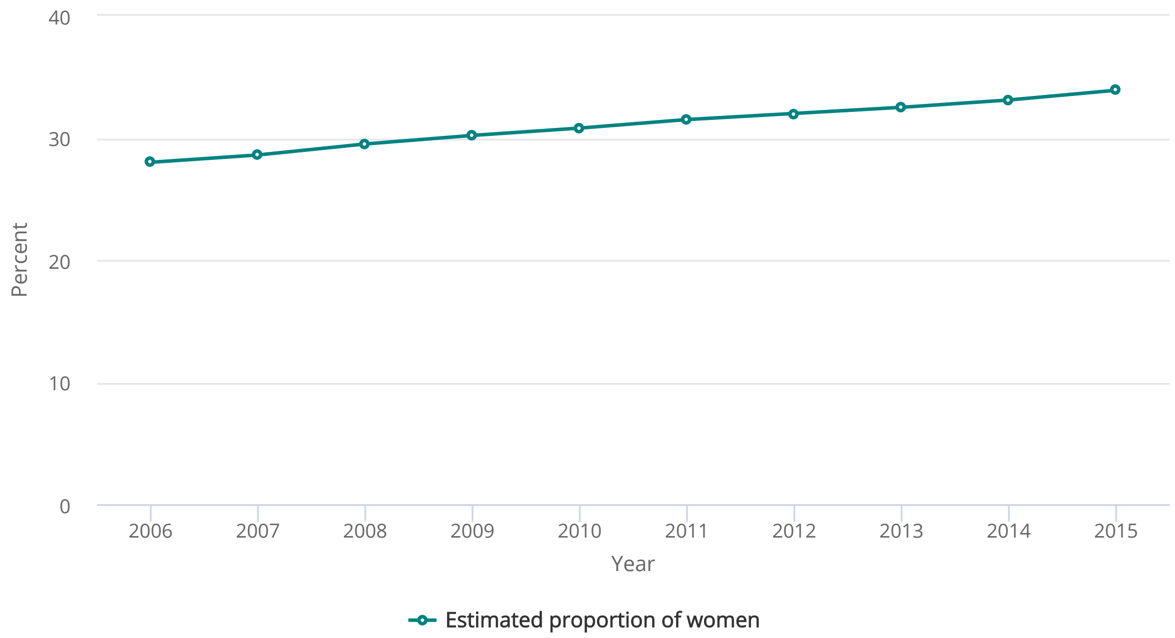
SIDEBAR

S&E Publication Patterns, by Gender

Recently, researchers have begun matching publication authorship data with name databases containing gender identifiers such as Social Security (Lariviére et al. 2013) or Genderize.io (Elsevier 2017). This sidebar summarizes research from Science-Metrix using Scopus bibliometric data and Namsor for estimating author gender (Science-Metrix 2017b).* Because of the various sources of uncertainty associated with matching name with gender, the analyses presented in this sidebar should be seen as exploratory research and interpreted with caution. Researchers are finding that although male authors historically comprised a larger share of peer-reviewed scientific publications, female authorship is growing. Science-Metrix estimates that from 2006 to 2015, female scientific authorship increased over 20% and reached nearly 34% in 2015 (Figure 5-G). Other researchers (Lariviére et al. 2013) have coined the term “productivity paradox” to discuss the current phenomenon where men publish more papers on average, even though there are more female than male undergraduate and graduate students in many countries. Gender balance is said to occur when women make up 40%–60% of any group (European Commission 2015).

FIGURE 5-G

Trends in the proportion of female authors of S&E publications in Scopus: 2006–15



Note(s)

Data are presented according to publication year. The 2015 data are preliminary and do not represent total 2015 publications.

Source(s)

Science-Metrix; NamSor, accessed October 2016; Elsevier, Scopus abstract and citation database, accessed August 2016.

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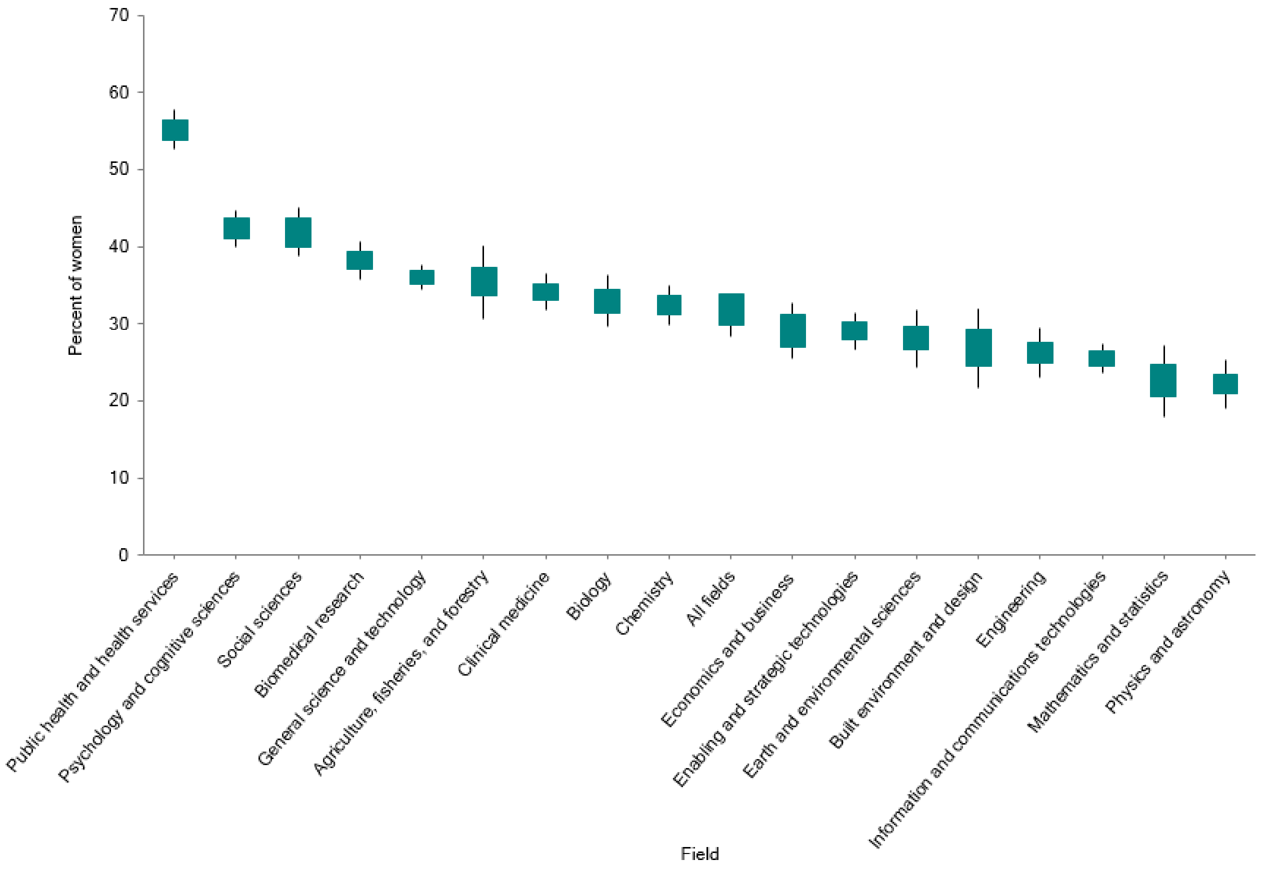
The gender of authors differs across research fields.† Science-Metrix finds that over the last decade, the research field with the highest proportion of female authorship is public health and health services; this is also the only field where women represent a larger share of authorship than men (Figure 5-H). Psychology and cognitive sciences and social sciences are all at or above the 40% mark. Six other fields are above 30%, and the remaining 8 fields are below 30% (which is the overall average across Scopus for the 2006–15 period).

FIGURE 5-H

Proportion of female authors of S&E publications, by field: 2006–15



Note(s)

Rectangle is the 95% confidence interval for NamSor only. The line is the 95% confidence interval due to the sampling error.

Source(s)

Science-Metrix; NamSor, accessed October 2016; Elsevier, Scopus abstract and citation database, accessed August 2016.

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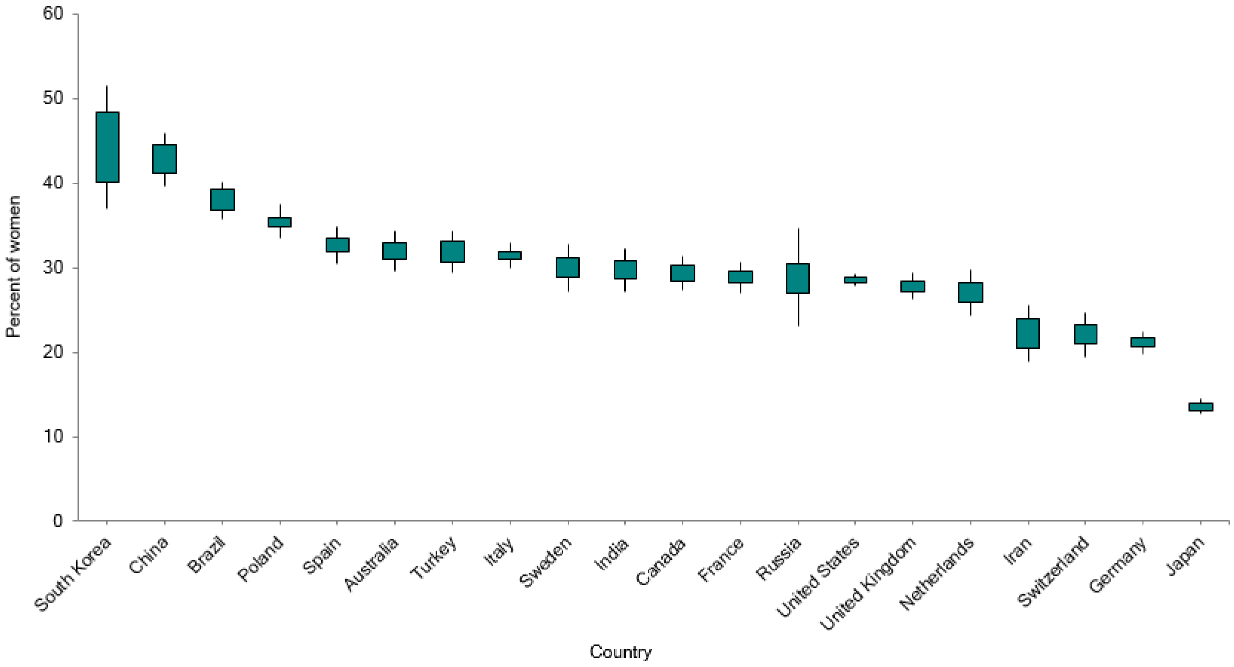
Among the 20 countries that produce the most academic articles, female authorship in Scopus (over the 2006–15 period) measured highest for South Korea and China, which all scored above the 40% mark (Figure 5-I). In the United States, women account for just under 30% of U.S. authorship. Two countries, South Korea and China, achieve gender parity with 40% or more of women in authorship, 6 more are near parity with above 30%, 11 more (including the United States) are above 20%, and Japan is around 13%.

FIGURE 5-I

Proportion of female authors of S&E publications, by country: 2006–15



Note(s)

The rectangle is the 95% confidence interval for NamSor only. The line is the 95% confidence interval due to the sampling error. Twenty leading academic article-producing countries are included.

Source(s)

Science-Metrix; NamSor, accessed October 2016; Elsevier, Scopus abstract and citation database, accessed August 2016.

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These results summarize Science-Metrix research using a name-based gender identification tool in conjunction with the Scopus database to estimate a probability for correctly identifying gender, based on an author's full name (given name and family name, though given name is usually more informative). For example, Helen is clearly female, but Riley is 40% male. The name-gender matched data set therefore introduces some uncertainties into the analysis because some names are not gender specific, especially for countries in East Asia, and those authorships that cannot be tagged with a high degree of certainty are removed from the analyzed population.[‡]

Further uncertainties exist in the analysis because Scopus has some coverage limits in non-English speaking countries (e.g., Russia), and some fields or editorial policies promote the use of initials rather than an author's given name (astronomy). Over time, the availability of full first names (as opposed to initials only) has risen in the Scopus database, approaching 70% in 2002 and 2003, and has been consistently close to 80% since 2013.

[*] The Namsor tool is used to code gender and provides a probability for correctly identifying gender (http://www.namsor.com/).

[†] Note that definitions of fields and countries are those of Science-Metrix, not those used elsewhere in *Indicators.*

[‡] To create estimates of sampling error for these proportions, Science-Metrix assumes that the authors who are identified by gender in the database are fully representative of the author population as a whole, including those for whom gender cannot be determined. Confidence interval estimates have been calculated under this assumption, but major differences between the gender distribution of those whose gender can be identified and those that are of unknown gender could result in other sources of uncertainty.

Trends in Citation of S&E Publications

The publication counts and collaboration rates described previously provide partial indicators of the quantity of S&E research output and the ties between researchers. Citations provide an additional indicator of the impact of research on subsequent work (Martin and Irvine 1980). This section provides indicators of S&E publications that are cited in other S&E publications. Citations indicate impact and are increasingly international in character, with publications authored in one country citing those authored in other countries. An increase in citation trends potentially indicates stronger international ties, or it can indicate changes in quality of research *outside* the country or region. Measured by average citation rates and by the shares of the most highly cited publications, the developed world continues to maintain a substantial impact advantage over the developing world. Nevertheless, the developing world is making rapid gains.

The next sections examine two aspects of publication citations in a global context: the overall citation rate of a country's scientific publications, and the share of the world's most highly cited literature authored by different countries. The discussion of publication citations will conclude with an examination of citations to publications authored by researchers at U.S. academic institutions and in other U.S. sectors.

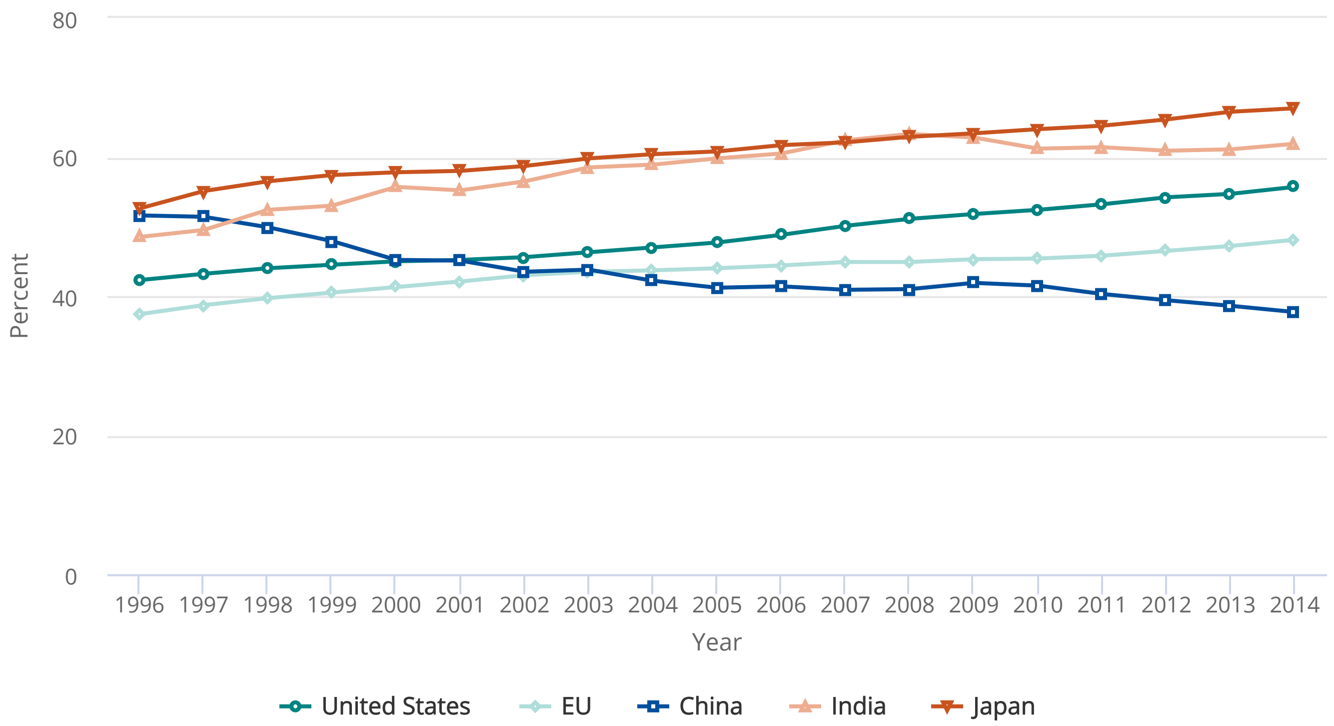
The rate of citations to S&E literature vary across fields of science and frequently peak within a few years after publication. However, even old publications can "awaken" to receive citations many years after publication (Ke et al. 2015). The average of relative citations (ARC) presented in this chapter is an index designed to allow for lags of varying length and to normalize across fields of research (see sidebar Bibliometric Data and Terminology). In contrast, when looking at the share of a country's citations that come from an international source, data presented in this report are calculated based on only the subsequent 24–36 months after publication, depending on the month in which a publication initially appears.

International Citation Patterns

Between 2004 and 2014, the share of citations to U.S. publications that come from abroad increased from 47.0% to 55.7% (Figure 5-27). The relative shares of foreign citations increased in most countries of the world over that same period (Appendix Table 5-47). By contrast, China's international share of citations decreased, from 42.2% in 2004 to 37.7% in 2014. However, the international share of a publication's use in citations tends to decrease as a country's domestic publication volume grows. Thus, changes in international citations for China were to be expected; China dramatically increased its output in recent years, so the associated decrease in its international share of citations supports the overall trend. The inverse relationship also holds because the U.S. share of total world output has decreased and the international share of U.S. citations has grown. Similarly, between 2004 and 2014, almost three-quarters (21) of the 28 countries in the EU increased their international share of citations (Appendix Table 5-47), and the EU as a unit increased its external share of citations from 43.7% to 48.1%, all while Europe's share of global output has gradually decreased. One country that does not follow this pattern is India, whose output volume and international share of citations have been increasing (Figure 5-22 and Figure 5-27); additionally, India's international share of citations fluctuates year over year. Further investigation may determine whether these observations result from changes in the database coverage over time or whether underlying changes in India's research ecosystem explain these phenomena.

FIGURE 5-27

Share of citations to selected region, country, or economy that are received from authors abroad: 1996–2014



EU = European Union.

Note(s)

Articles refer to publications from a selection of journals, books, and conference proceedings in S&E from Scopus. Articles are classified by their year of publication and are assigned to a region, country, or economy on the basis of the institutional address(es) listed in the article. Citations are presented for the year in which the cited article was published, showing the counts of subsequent citations from peer-reviewed literature. At least 2 years of data after publication are needed for a meaningful measure. See Appendix Table 5-47.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; Elsevier, Scopus abstract and citation database, accessed July 2017.

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The patterns of international citations between country pairs shows the impact of one country's S&E publications on another country's S&E researchers. The relative citation index normalizes cross-national citation data for variations in relative size of publication output, much like the collaboration index (see sidebar Bibliometric Data and Terminology). The expected value is 1.00, but unlike the collaboration index, citation index scores are not symmetric. For example, if country A cites publications by country B 15% more often than expected, that does not mean that country B also cites publications by country

A 15% more than expected. ▦ Table 5-28 shows the relative citation index for 2014 for major publishing locations in four regions: North America, South America, the EU, and Asia. These data show the following:

- From among the major producers of S&E publications, U.S. publications cite publications from Canada (1.15) and the United Kingdom (1.13) more than expected, based on size.
- U.S.-based authors cite Chinese (0.31), Indian (0.20), and other Asian S&E publications less than expected.
- Publications by Mexican researchers are heavily cited in publications from Argentina and Chile. Likewise, Mexican researchers cite publications by South American authors more than they cite publications from other areas of the world.
- Inter-European influence is strong, with France, Germany, and United Kingdom country pairs exhibiting index values greater than 1.0 (with the exception of the United Kingdom citing France, which occurs at the expected rate).

Similar to the coauthorship patterns, these data indicate the strong influence that geographic, cultural, and linguistic ties have on citation patterns.

TABLE 5-28

Relative citation index, by selected region, country, or economy pair: 2014

(Relative citation index)

Citing region, country, or economy	Cited region, country, or economy													
	North America			South America			EU			Asia				
	Canada	Mexico	United States	Argentina	Brazil	Chile	France	Germany	United Kingdom	China	India	Japan	South Korea	Taiwan
North America														
Canada	9.09	0.34	1.49	0.41	0.35	0.55	0.89	0.91	1.34	0.37	0.25	0.46	0.50	0.43
Mexico	0.95	27.95	1.00	1.69	1.14	1.60	0.88	0.77	0.94	0.55	0.82	0.51	0.72	0.70
United States	1.15	0.29	2.93	0.37	0.27	0.43	0.76	0.88	1.13	0.31	0.20	0.50	0.49	0.39
South America														
Argentina	0.96	1.47	1.02	54.11	1.56	3.24	1.08	0.95	1.02	0.38	0.50	0.43	0.47	0.42
Brazil	0.93	1.10	0.86	1.80	12.60	1.21	0.82	0.71	0.89	0.42	0.65	0.41	0.56	0.54
Chile	1.21	1.33	1.10	2.91	1.02	62.47	1.07	0.94	1.14	0.40	0.46	0.48	0.57	0.48
EU														
France	1.05	0.39	1.16	0.60	0.39	0.63	7.72	1.23	1.30	0.32	0.26	0.61	0.47	0.39
Germany	0.95	0.27	1.18	0.43	0.29	0.46	1.07	6.28	1.32	0.31	0.21	0.60	0.47	0.34
United Kingdom	1.17	0.29	1.29	0.36	0.31	0.49	1.00	1.15	6.10	0.30	0.23	0.50	0.41	0.36
Asia														
China	0.69	0.36	0.80	0.38	0.29	0.34	0.55	0.63	0.61	2.73	0.58	0.65	1.11	0.96

Citing region, country, or economy	Cited region, country, or economy													
	North America			South America			EU			Asia				
	Canada	Mexico	United States	Argentina	Brazil	Chile	France	Germany	United Kingdom	China	India	Japan	South Korea	Taiwan
India	0.65	0.62	0.65	0.52	0.49	0.40	0.54	0.58	0.65	0.86	7.52	0.50	0.99	0.99
Japan	0.76	0.24	1.04	0.31	0.25	0.34	0.82	0.97	0.91	0.47	0.29	7.79	0.87	0.64
South Korea	0.71	0.34	1.00	0.34	0.30	0.41	0.56	0.69	0.70	0.86	0.61	0.86	10.47	1.21
Taiwan	0.81	0.37	0.98	0.38	0.36	0.38	0.63	0.66	0.78	0.91	0.59	0.81	1.42	16.55

EU = European Union.

Note(s)

Citations refer to publications from a selection of journals, books, and conference proceedings in S&E from Scopus. Articles are classified by their year of publication and are assigned to a region, country, or economy on the basis of the institutional address(es) listed in the article. Articles are credited on a fractional-count basis (i.e., for articles with collaborating institutions from multiple regions, countries, or economies, each region, country, or economy receives fractional credit on the basis of the proportion of its participating institutions). Citation counts are based on all citations made to articles in their publication year and in the 2 following years (i.e., a 3-year citation window; for instance, scores in 2012 are based on citations to articles published in 2012 that were made in articles published in 2012–14).

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; Elsevier, Scopus abstract and citation database, accessed July 2017.

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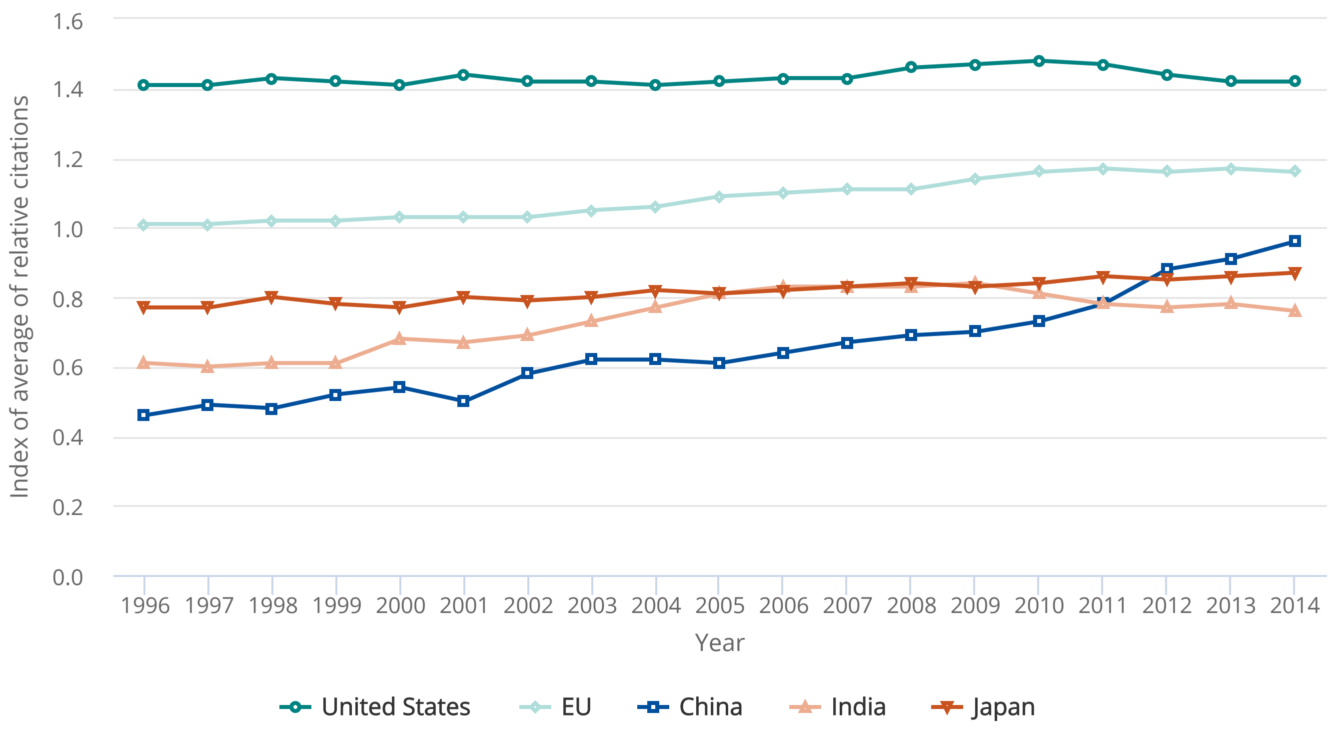
The ARC scores are calculated to allow for citation lags of varying lengths and to normalize for field of research (see sidebar Bibliometric Data and Terminology). Appendix Table 5-50 provides the ARC scores for 1996–2014 for countries and regions with enough publications to compute robust scores. Through 2014, the U.S. ARC score held steady around 1.40, or 40% more citations than would be expected, based on the number of peer-reviewed publications and representation by field. China's ARC score rapidly increased across 2004–14, from 0.62 to 0.96, improving from 38% fewer citations than would be expected, based on size, to just reaching the expected level of citations.

When viewed as a group, the countries of the EU increased from slightly more citations than would be expected based on size (1.06) in 2004, to nearly 10% more (1.16) in 2014, based on ARC scores (Figure 5-28). Appendix Table 5-50 provides country-level measures for the EU that show that Belgium, Cyprus, Denmark, Estonia, Finland, Ireland, the Netherlands, Sweden, and the United Kingdom had the highest ARC scores in 2014 (all at or above 1.50). In East and Southeast Asia, Singapore had the highest ARC score, reaching 1.83 in 2014.

At the field level, the average impact of U.S. publications is also higher than would be expected. U.S. citation impacts for computer sciences publications are especially high, at 69% higher than the world average value. Although the 2014 U.S. citation impacts remain above the world average for all fields combined—and individually for each of the 13 broad fields of science—average U.S. impact has been decreasing between 2004 and 2014 in engineering, mathematics, chemistry, social sciences, and psychology, while U.S. physics ARC remained unchanged during that period (Figure 5-29).

FIGURE 5-28

Average relative citations, by region, country, or economy: 1996–2014



EU = European Union.

Note(s)

Articles are classified by the publication year and are assigned to a region, country, or economy on the basis of the institutional address(es) listed in the article. The average of relative citations is presented for the year of publication showing the counts of subsequent citations from peer-reviewed literature. At least 2 years of data after publication are needed for a meaningful measure. See Appendix Table 5-50.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; Elsevier, Scopus abstract and citation database, accessed July 2017.

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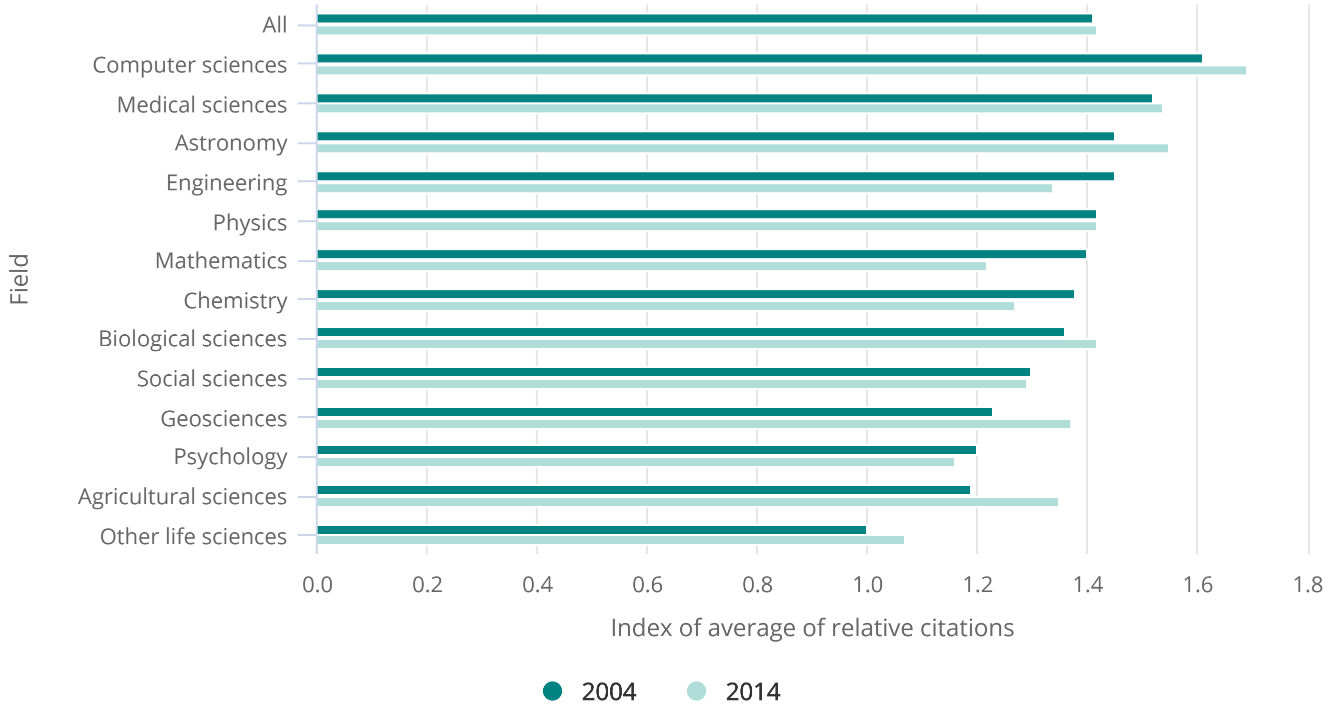
FIGURE 5-29

Average relative citations for the United States, by S&E field: 2004 and 2014



Note(s)

Articles are classified by the publication year and are assigned to a region, country, or economy on the basis of the institutional address(es) listed in the article. The average of relative citations is presented for the year of publication showing the counts of subsequent citations from peer-reviewed literature. At least 2 years of data after publication are needed for a meaningful measure. See Appendix Table 5-49.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; Elsevier, Scopus abstract and citation database, accessed July 2017.

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Trends in Highly Cited S&E Literature, by Country

Among all publications, only a small share receives more than a few citations. Publications that are in the top 1% of total global citations, adjusted for field and year, can be considered to have the highest impact. Citations are indexed to show a country's share of publications among the world's top 1% most-cited literature. This top 1% of publications can be segmented by authors' institutional addresses to show which countries and regions are producing these high-impact S&E publications. Similar to the ARC, country and region contribution rates for highly cited publications need to be normalized for the share of total publications produced by each country. This indicator is based on the expectation that if highly cited publications were evenly distributed, every country would have 1% of its publications among the top 1% of publications ranked on the basis of citation. If 2% of a country's publications are among the top 1% of all cited publications, the country has twice as many highly cited publications than would otherwise be expected, based on its number of publications.

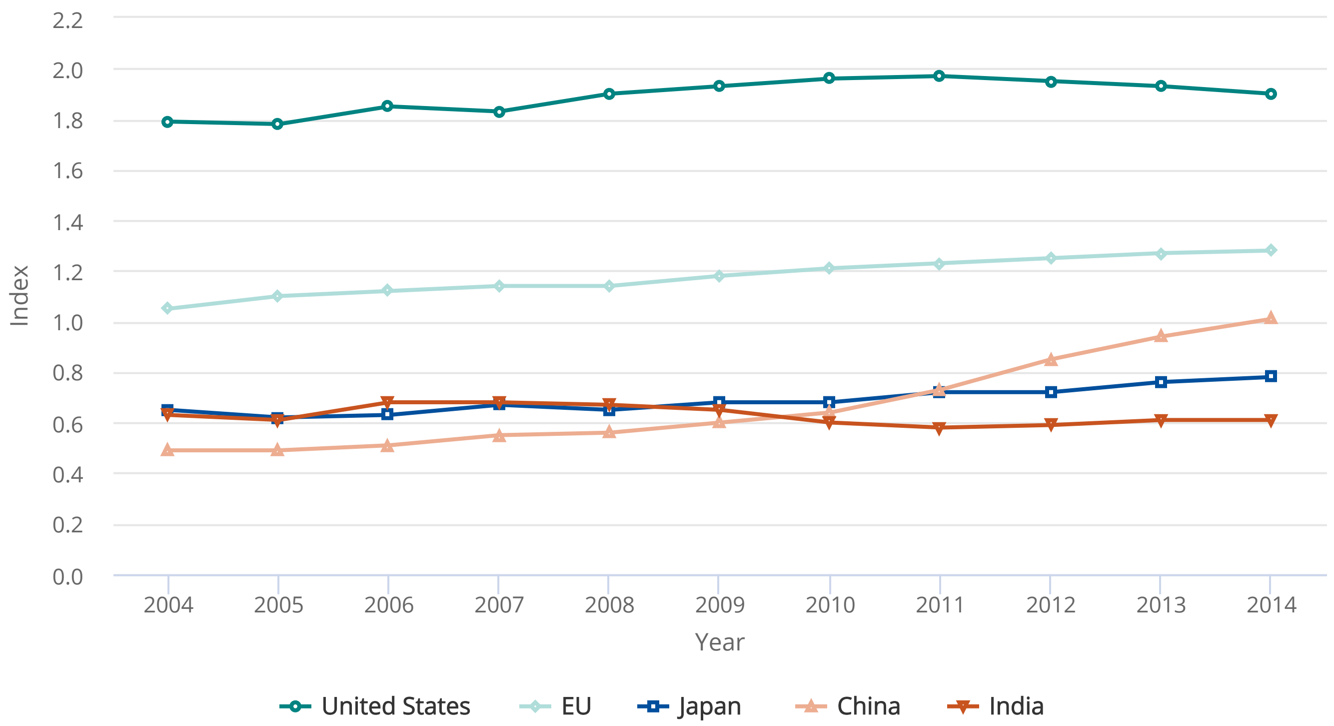
World citations to U.S. research publications show that, in all broad fields of S&E, U.S.-based researchers continue to produce a larger-than-expected percentage of the top 1% most highly cited publications. Even when normalized for U.S. overall publication output, the U.S. share is one of the highest among major S&E producers. Of publications that appeared in 2014, almost 2% of U.S.-authored publications are among the top 1% of publications, ranked by citation. This pattern of U.S. publications receiving more citations than expected holds throughout the top half of the percentile distribution; U.S. publications are more likely to be in the top 5%, 10%, and 20% and are less likely to be in the bottom 50% of the distribution of articles, based on relative citations (Appendix Table 5-48).

U.S. publications in the fields of agricultural sciences, astronomy, biological sciences, computer sciences, geosciences, medical sciences, and physics are a growing share of the top 1% most-cited articles worldwide, with about twice as many U.S. publications in this elite set in 2014 than would be expected, based on output volume. In three fields—chemistry, engineering, and mathematics—the U.S. relative share of the top 1% of articles declined between 2004 and 2014 but held constant for social sciences (Appendix Table 5-48).

Between 2004 and 2014, China and the EU experienced more rapid growth than the United States in their share of the world's most highly cited publications (Figure 5-30). The share of China's publications among the top 1% of publications ranked by citation increased from 0.49 to 1.01. China's scores on the top 1% most-cited scholarly literature by research field are highest in chemistry, computer sciences, mathematics, other life sciences, and social sciences (Appendix Table 5-48).

FIGURE 5-30

Share of S&E publications in the top 1% of most cited publications, by selected region, country, or economy: 2004–14



EU = European Union.

Note(s)

This figure depicts the share of publications that are in the top 1% of the world's citations, relative to all the country's publications in that period and field. It is computed as follows: *Sx* = *HCPx*/*Px*, where *Sx* is the share of output from country *x* in the top 1% most-cited articles; *HCPx* is the number of articles from country *x* that are among the top 1% most-cited articles in the world; and *Px* is the total number of papers from country *x* in the database that were published in 2014 or earlier. Citations are presented for the year of publication, showing the counts of subsequent citations from peer-reviewed literature. At least 2 years of data after publication are needed for a meaningful measure. Publications that cannot be classified by country or field are excluded. Articles are classified by the publication year and are assigned to a region, country, or economy on the basis of the institutional address(es) listed in the article. The world average stands at 1.00% for each period and field. See Appendix Table 5-26 for countries included in the EU. See Appendix Table 5-51.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; Elsevier, Scopus abstract and citation database, accessed July 2017.

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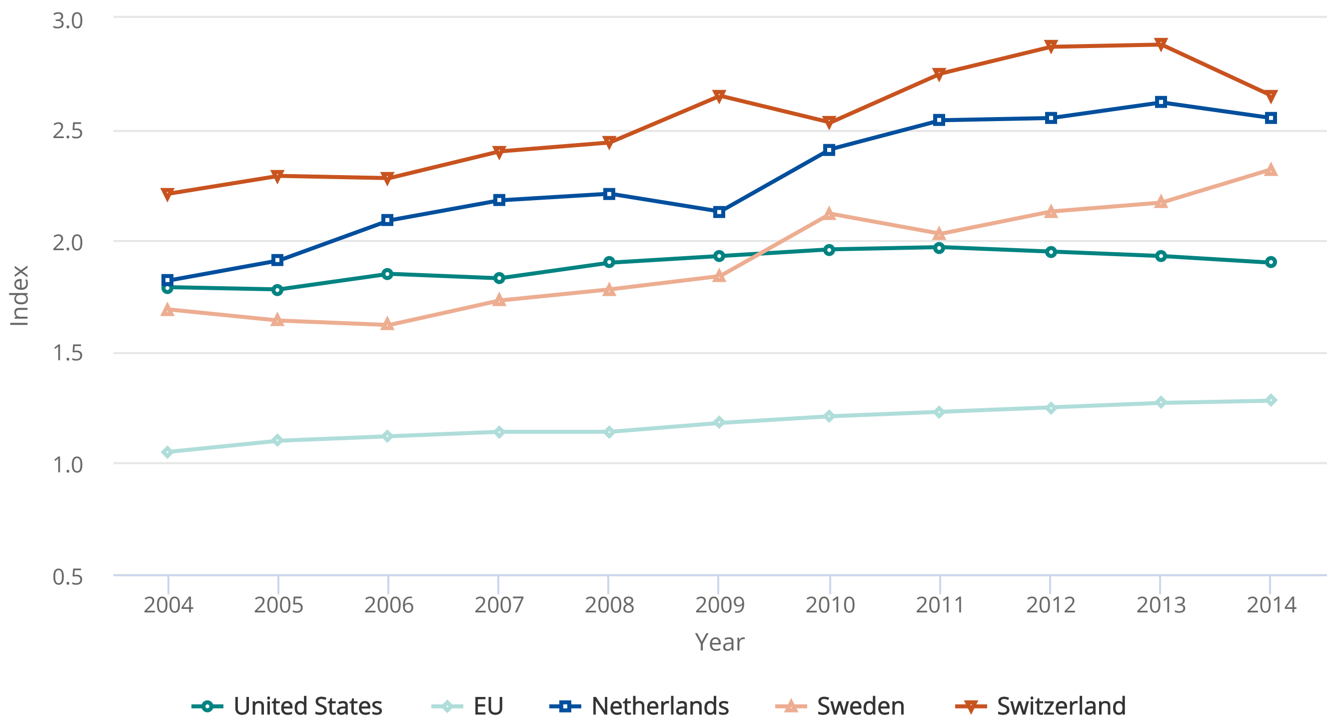
During this same period, several of the smaller research-intensive nations of the EU have made gains in their relative share of the top 1% of highly cited publications—notably, Austria, Belgium, Cyprus, Denmark, Estonia, Finland, Greece, Ireland, Luxembourg, the Netherlands, and Sweden (Appendix Table 5-51). Each of these nations had a larger share than that of the United States in 2014. Figure 5-31 shows the top 1% shares for the United States, the EU, the Netherlands, Sweden, and Switzerland. Among other European nations with over 15,000 publications, Belgium, Czech Republic, France, Germany, Italy, Spain, and the United Kingdom were at or above 1% shares in recent years.

FIGURE 5-31

S&E publication output in the top 1% of cited publications, by selected region, country, or economy: 2004–14



EU = European Union.

Note(s)

This figure depicts the share of publications that are in the top 1% of the world's citations, relative to all the country's publications in that period and field. It is computed as follows: *Sx* = *HCPx*/ *Px*, where *Sx* is the share of output from country *x* in the top 1% most-cited articles; *HCPx* is the number of articles from country *x* that are among the top 1% most-cited articles in the world; and *Px* is the total number of papers from country *x* in the database that were published in 2014 or earlier. Citations are presented for the year of publication, showing the counts of subsequent citations from peer-reviewed literature. At least 2 years of data after publication are needed for a meaningful measure. Publications that cannot be classified by country or field are excluded. Articles are classified by the publication year and are assigned to a region, country, or economy on the basis of the institutional address(es) listed in the article. The world average stands at 1.00% for each period and field. See Appendix Table 5-26 for countries included in the EU. See Appendix Table 5-51.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; Elsevier, Scopus abstract and citation database, accessed July 2017.

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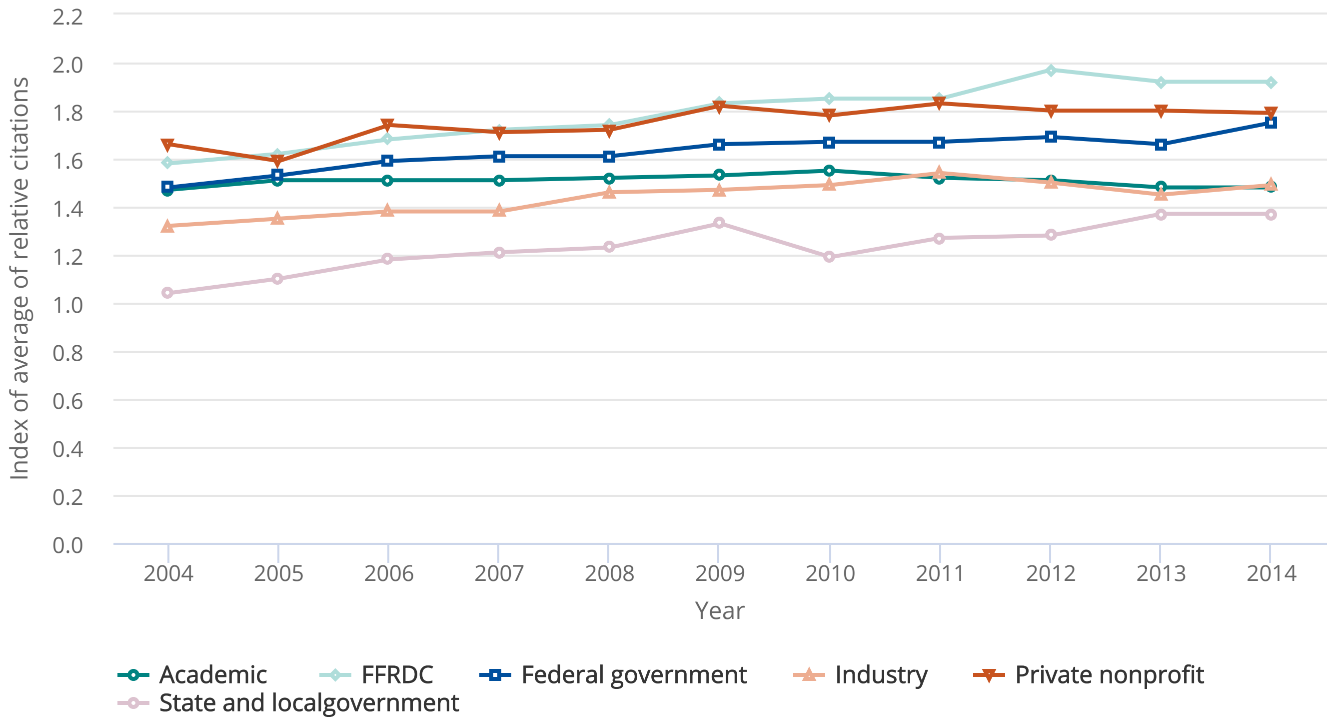
U.S. Sector Citation Trends

Relative citations can also be used to examine the citation impact of publications by each U.S. sector. 📊 Figure 5-32 shows the index values for each of the six sectors of U.S. institutions relative to world output, normalized by field, and how they have changed between 2004 and 2014. U.S. academic publications, which make up the vast majority of U.S. publications, held constant at about 50% more citations on average than would be expected. Publications authored at FFRDCs have shown a marked improvement since 2004; in 2014, they received the highest index value of all U.S. sectors—almost 90% more citations on average than would have been expected.

FIGURE 5-32

Average relative citations for U.S. S&E articles, by sector: 2004–14



FFRDC = federally funded research and development center.

Note(s)

Articles refer to publications from a selection of journals, books, and conference proceedings in S&E from Scopus. Articles are classified by their year of publication and are assigned to a region, country, or economy on the basis of the institutional address(es) listed in the article. Citations are presented for the year in which the cited article was published, showing the counts of subsequent citations from peer-reviewed literature. At least 3 years of data after publication are needed for a meaningful measure. Data are incomplete for 2014.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; Elsevier, Scopus abstract and citation database, accessed December 2016.

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[1] For more information on the International Monetary Fund economic classification of countries, see https://www.imf.org/external/pubs/ft/weo/2016/01/weodata/groups.htm.

[2] Country assignments refer to the institutional address of authors, with partial credit given for international coauthorship. See sidebar Bibliometric Data and Terminology for more information on how S&E article production and collaboration are measured.

[3] Calculated from Appendix Table 5-27 and the International Monetary Fund definition of developing countries.

[4] The English-language bias in Scopus understates the “true” number of publications from China.

[5] In 2015, 7.4% of the U.S. publications could not be assigned to a sector based on the information in the Scopus database.

[6] See the Master Government List of Federally Funded R&D Centers at https://www.nsf.gov/statistics/ffrdclist/.

[7] Note that coauthorship counts use *whole counting*, which means that a publication with a foreign coauthor and a domestic author from a different sector will be counted as a coauthored paper with another U.S. sector and counted as coauthored with a foreign institution.

Conclusion

The nation’s universities and colleges play a key role in U.S. R&D by providing the following services:

- Educating and training S&E students in research practices and other advanced skills
- Performing a large share of the nation’s basic research
- Building and operating world-class research facilities and supporting the national research cyberinfrastructure
- Producing intellectual output through published research articles and patents

Over the past several decades, academic expenditures on R&D have continued to increase, with slowing growth trends in recent years. Although the federal government has long provided the majority of funding for academic R&D through research grants and contracts, its share of total academic R&D funding has declined in recent years. The percentage paid for by universities and colleges, meanwhile, has increased markedly in recent years, but these funds do not replace federal research funds *in kind*. Other important sources of academic R&D funding are state and local governments, businesses, and nonprofit organizations.

Academic R&D expenditures have long been concentrated in a relatively small number of universities. For the last quarter century, fewer than 12 universities each year have received about one-fifth of total academic R&D funding, about 20 universities have received close to one-third of this funding, and about 100 have received four-fifths of the total. (The identities of the universities in each group have somewhat varied over time.)

For decades, more than half of all academic R&D spending has been in the broad field of life sciences. However, over the past decade, spending on engineering R&D has outpaced growth in spending in the sciences in the aggregate.

About one-third of all U.S.-trained, academically employed S&E doctorate holders received their degree in life sciences. (In 2015, just over 55% of their foreign-trained counterparts had doctorates in life sciences.) The dominance of life sciences is also seen in physical infrastructure, where two subfields of life sciences—biological sciences and biomedical sciences—account for the bulk of growth in research space and where the largest share of new university research construction has been undertaken to advance health and clinical sciences.

The structure of academic employment of S&E doctorate holders within the nation’s universities and colleges has undergone substantial changes over the past 20–30 years. Although full-time faculty positions in the professoriate continue to be the norm in academic employment, S&E doctorate holders are increasingly employed in part-time and nontenured positions. Since 1995, the percentage of doctorate holders with tenured positions has decreased even as the academic doctoral workforce has aged. The share of academic researchers receiving federal support, including early career S&E faculty, has declined since 1991. Funding success rates have declined at NIH and NSF over the past 15 years.

Higher education has also experienced notable changes in demographic diversity. In particular, the proportion of academic doctoral positions held by white, male, native-born citizens has declined. Women represent a growing proportion of academic doctoral employment in S&E, as do the foreign born and foreign trained. The proportion of Asians or Pacific Islanders employed in the S&E academic doctoral workforce has grown dramatically over the past three decades, while the shares held by blacks, Hispanics, and American Indians or Alaska Natives have grown much more slowly; these latter groups remain underrepresented in the academic doctoral workforce.

There have been further shifts in the degree to which the academic doctoral workforce is focused on research activities versus teaching. Among full-time doctoral S&E faculty, priority shifted from teaching to research from 1973 to 2003; since 2003, however, the proportions of faculty who primarily teach and those who primarily conduct research have remained relatively stable. Of those in the academic doctoral workforce reporting research as their primary activity, two-thirds are employed at the nation's most research-intensive academic institutions. Those who primarily teach are more evenly distributed across academia.

Overall, the United States remains the most influential individual nation in its contribution to S&E publications, based on overall size of the U.S. contribution and its relative impact, as measured by citations in S&E publications. The bibliometric data described in this chapter show U.S. research maintaining global strength in the life sciences, as demonstrated by publication output and citations.

In terms of S&E research quantity, but not impact, China produced the most S&E publications in 2016. Growth trends in S&E publications reflect the spread of overall economic and social development across the world. Building from a higher base, the developed world, including the United States, the EU, and Japan, is growing more slowly in S&E publications, and developing nations are increasing production more quickly.

In addition to the increased performance in the developing world, individual nations within the EU and the developed world have emerged as research hubs, as demonstrated by their citations. International research collaboration is increasing, reflecting traditional cross-country ties and new ones that stem from growing capabilities in the developing world. This international collaboration and the accompanying rise in international citations indicate that S&E knowledge is flowing with increasing ease across the world. Unlike the competition for finite resources, the creation of S&E research adds to the knowledge base available for use worldwide—a communal supply on which more and more countries can capitalize as research capacities increase globally.

Glossary

Definitions

Average of relative citations (ARC): The ARC is a citation measure normalized across fields of science and years of publication to correct for differences in the frequency and timing of citations. Dividing each publication's citation count by the average citation count of all publications in that subfield in that same year creates a relative citation. Then, for a given geography or sector, these relative citations for each publication are averaged to create an ARC.

Doctoral academic S&E workforce: Includes those with a research doctorate in science, engineering, or health who are employed in 2- or 4-year colleges or universities, including medical schools and university research institutes, in the following positions: full and associate professors (referred to as *senior faculty*); assistant professors (referred to as *junior faculty*); postdoctorates (postdocs); other full-time positions, such as instructors, lecturers, adjunct faculty, research associates, and administrators; and part-time positions of all kinds. Unless otherwise specified, these individuals earned their doctorate at a U.S. university or college.

European Union (EU): The EU comprises 28 member nations: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, and the United Kingdom. Unless otherwise noted, Organisation for Economic Co-operation and Development data on the EU include all 28 nations.

Federally funded research and development center (FFRDC): R&D organization exclusively or substantially financed by the federal government, to meet particular R&D objectives or, in some instances, to provide major facilities at universities for research and associated training purposes. An industrial firm, a university, or a nonprofit institution administers each FFRDC.

Fractional counting: Method of counting S&E publications in which credit for coauthored publications is divided among the collaborating institutions or countries based on the proportion of their participating authors.

Index of highly cited articles: A country's share of the top 1% most-cited S&E publications divided by the country's share of all S&E publications. An index greater than 1.00 means that a country contributed a disproportionately larger share of highly cited publications; an index less than 1.00 means a smaller share.

Index of international collaboration: Country A's rate of coauthorship in country B's international collaborations, divided by country B's overall international collaboration rate. Values are symmetrical for country-country pairs. An index greater than 1.00 means that a country-country pair has a stronger-than-expected tendency to collaborate; an index less than 1.00 means a weaker-than-expected tendency to collaborate.

Net assignable square feet (NASF): Unit for measuring research space. NASF is the sum of all areas on all floors of a building assigned to, or available to be assigned to, an occupant for a specific use, such as research or instruction. NASF is measured from the inside face of walls.

Relative citation index: Country A's share of citations to country B's S&E publications divided by total citations to country B's S&E publications. An index of greater than 1.00 means that the country has a higher-than-expected tendency to cite the other country's S&E literature; an index less than 1.00 means a lower-than-expected tendency to cite the other country's literature.

Research space: The budgeted and accounted-for space used for sponsored R&D activities at academic institutions. Research space is the net assignable square feet of space in buildings within which research activities take place. Research facilities are located within buildings. A building is a roofed structure for permanent or temporary shelter of people, animals, plants, materials, or equipment. Structures are included as research space if they are (1) attached to a foundation; (2) roofed; (3) serviced by a utility, exclusive of lighting; and (4) a source of significant maintenance and repair activities.

Underrepresented minority: Racial and ethnic groups, including blacks, Hispanics, and American Indians or Alaska Natives, which are considered to be underrepresented in academic S&E employment.

Key to Acronyms and Abbreviations

ADEA: Age Discrimination in Employment Act of 1967

ARC: average of relative citations

ARRA: American Recovery and Reinvestment Act

DOAJ: Directory of Open Access Journals

DOD: Department of Defense

DOE: Department of Energy

EPA: Environmental Protection Agency

EPSCoR: Established Program to Stimulate Competitive Research

EU: European Union

FFRDC: federally funded research and development center

FY: fiscal year

HERD: Higher Education Research and Development Survey

HHS: Department of Health and Human Services

HPC: high-performance computing

NASA: National Aeronautics and Space Administration

NASF: net assignable square feet

NCSES: National Center for Science and Engineering Statistics

nec: not elsewhere classified

NIH: National Institutes of Health

NSCG: National Survey of College Graduates

NSCI: National Strategic Computing Initiative

NSF: National Science Foundation

OA: open access

R&D: research and development

RC: relative citation

S&E: science and engineering

SciELO: Scientific Electronic Library Online

SDR: Survey of Doctorate Recipients

UK: United Kingdom

URM: underrepresented minority (black or African American, Hispanic or Latino, and American Indian or Alaska Native)

USDA: Department of Agriculture

WebCASPAR: Integrated Science and Engineering Resources Data System

XSEDE: Extreme Science and Engineering Discovery Environment

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CHAPTER 6

Industry, Technology, and the Global Marketplace

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Highlights

Knowledge and Technology Industries in the World Economy

Knowledge- and technology-intensive (KTI) industries are a major part of the global economy.

- Fifteen KTI industries, consisting of five knowledge-intensive services industries, five high-technology manufacturing industries, and five medium-high-technology industries, represented nearly one-third of world gross domestic product (GDP) in 2016.
- The commercial knowledge-intensive services—business, financial, and information—have the highest share of GDP (15%). The public knowledge-intensive services—education and health care—have a 9% share; these are publicly regulated or provided and remain relatively more location bound than the commercial knowledge-intensive services.
- The medium-high-technology manufacturing industries—motor vehicles and parts, electrical machinery, machinery and equipment, chemicals excluding pharmaceuticals, and railroad and other transportation equipment—are the third largest (4%).
- The high-technology manufacturing industries—aircraft and spacecraft; communications and semiconductors; computers; pharmaceuticals; and testing, measuring, and control instruments—account for a 2% share of world GDP.
- The United States has the highest KTI share of GDP (38%) of any large economy closely followed by Japan (36%). The KTI share for the European Union (EU) is considerably lower.
- China has the largest KTI share of any large developing economy (35%), and its KTI share is comparable to those of large, developed economies. The KTI shares in other large developing economies are significantly lower than China's.

Worldwide Distribution of Knowledge- and Technology-Intensive Industries

The United States had the largest global share of commercial KI services in 2016.

- The United States accounted for 31% of global commercial KI services (business, financial, and information), followed by the EU (21%).
- China is the world's third largest provider of commercial KI services (17% global share). Despite a recent slowdown in its rapid pace of growth, China continues to grow far faster than the United States and other large developed economies.
- In high-technology manufacturing, the United States is the largest global producer (31% global share). The U.S. global share has remained stable for the last decade. China is the second largest global producer (24%). Rapid growth of China's industries more than doubled China's global share over the last decade. China surpassed Japan in 2008 and the EU in 2012.
- China is the world's dominant producer in medium-high-technology industries (32% global share). China's global share nearly tripled over the last decade, and it surpassed the United States in the late-2000s and the EU in the early-2010s.

U.S. KTI industries have had a stronger recovery from the global recession than those in the EU and Japan, as evidenced by output data starting in 2011.

- Value-added output of U.S. commercial knowledge-intensive services in 2016 was 26% higher than in 2011. Output in the EU and Japan declined.
- U.S. high-technology manufacturing industries grew 16% between 2011 and 2016. The EU's output grew slightly, and Japan's output was stagnant.
- Value-added output of U.S. medium-high-technology manufacturing industries was 17% higher in 2016 than in 2011. Output in the EU declined and Japan remained flat.

KTI industries play an important role in the U.S. economy and in U.S. business R&D.

- U.S. commercial KI services industries employ 17% of workers in all industries and fund 29% of U.S. business R&D.
- U.S. high-technology manufacturing industries employ 1.8 million workers and fund nearly half of U.S. business R&D.
- U.S. medium-high-technology industries employ 3.0 million workers and fund 11% of U.S. business R&D.
- U.S. KTI industries have had a strong recovery in their output, but gains in employment have been weaker. Employment in commercial KI services in 2016 was 1.2 million higher compared to 2007 prior to the recession. Although growing robustly following the global recession, employment in medium-high technology manufacturing industries remains slightly below its level prior to the global recession. Employment in high-technology manufacturing has remained stagnant and remains below its level prior to the global recession.

The United States is a major exporter of KTI services.

- The EU is the world's largest exporter of commercial KI services, followed by the United States; both have substantial surpluses in this area.
- The EU's commercial KI services exports grew 20% to reach more than $500 billion (33% global share) between 2011 and 2016.
- U.S. exports of commercial KI services grew faster than the EU's over this period, reaching $288 billion (18% global share).
- China and India's KTI exports grew rapidly, resulting in their global export shares reaching 6%–7% in 2016.
- China is the world's largest exporter of high-technology products (24% global share), with a substantial surplus. However, intermediate inputs imported from other countries account for a large share of the value of China's exports. China's exports and trade surplus measured on a value-added basis are considerably lower.
- The EU is the world's second largest exporter of high-technology products (17% global share). The United States is the third largest exporter (12%) closely followed by Taiwan. The United States is the world's largest exporter of aircraft and spacecraft (43% global share).
- The U.S. trade deficit in high-technology goods is largely anchored in products in information and communications technologies—communications, computers, and semiconductors. The United States has a substantial trade surplus in aircraft and spacecraft.

- The EU is the world's largest exporter of medium-high-technology goods (25% global share) and has a substantial surplus. China is the second largest global exporter (20% share) and has a substantial trade surplus, as does third-place Japan (11%).
- The United States is the fourth largest exporter and has a substantial deficit in medium-high-technology goods. The United States has a sizeable deficit in motor vehicles and parts ($98 billion), and deficits of $40–$52 billion in electrical machinery and appliances and machinery and equipment.

Global Trends in Sustainable Energy Research and Technologies

Global private investment in sustainable energy technologies in 2016 was $260 billion, largely in solar and wind. China attracted the most investment of any country.

- Early-stage private investment in sustainable energy technologies, consisting of venture capital and private equity investment, was $7.5 billion in 2016. The United States attracted the most venture capital and private equity of any country ($3.5 billion). China attracted $2.2 billion, a record high, and far higher than in 2015 ($0.5 billion).
- Energy smart and solar are the leading technologies for venture and capital and private equity investment with biofuels and wind receiving far smaller amounts. Energy smart covers a wide range of technologies, from digital energy applications to efficient lighting, electric vehicles, and the smart grid that maximize the energy efficiency of existing energy sources and networks
- Global private investment in later-stage financing—to build utility-scale power plants and installations of solar in residential and commercial buildings—was $252 billion in 2016. Two technologies—wind and solar—dominate investment, each with a share of about 40%.
- China leads the world in attracting later-stage commercial investment in sustainable energy technologies (33% global share), followed by the EU (25%) and the United States (18%).
- Investment in sustainable energy technologies fell 19% in 2016 compared to 2015, the deepest annual decline over the last decade. Investment in China and Japan fell sharply, reflecting, in part, cutbacks in government incentives supporting the deployment of renewable energy and a greater emphasis on utilizing the existing renewable energy capacity in each of these countries more effectively.
- U.S. investment in 2016 ($46 billion) was 8% lower than in 2015. Investment in the United States has fluctuated in a range of $34 billion to $51 billion between 2011 and 2016 because of policy uncertainty. Solar investment has been the main driver of U.S. investment between 2010 and 2015.

The United States was the largest investor ($3.8 billion) in 2014 in public research, development, and demonstration (RD&D) of sustainable energy technologies. The EU is the second largest investor ($3.6 billion), followed by Japan ($2.7 billion).

- Global expenditures on public RD&D of sustainable energy technologies was an estimated $12.0 billion in 2014. Nuclear was the largest area, receiving $3.5 billion. The next two largest areas were energy efficiency ($3.3 billion) and renewables ($3.0 billion).
- Between 2011 and 2014, global expenditures of public RD&D fell from $14 billion to $12 billion, with declines in nuclear, renewables, and carbon capture and storage.

- Despite a decline in U.S. investment between 2011 and 2014, the United States surpassed the EU to become the world's largest investor in 2014. U.S. public RD&D investment in renewables and nuclear declined, while investment in energy efficiency increased.

The number of U.S. Patent and Trade Office patents granted in sustainable energy technologies doubled between 2009 and 2015. Six technologies—solar, hybrid and electric vehicles, smart grid, fuel cell, battery, capture and storage of carbon and other greenhouse gases—have led growth of these patents.

- U.S. inventors received the largest share of sustainable energy patents in 2016 (43%), followed by Japan (20%), and the EU (16%). Patenting by U.S. inventors has been led by four technologies—hybrid and electric vehicles, solar, smart grid, and energy storage.
- Patents granted to South Korea more than quadrupled between 2009 and 2016, led by growth in energy storage, solar, hybrid/electric, and battery technologies.

Introduction

Chapter Overview

Policymakers in many countries increasingly emphasize the central role of knowledge, particularly R&D and other activities that advance science and technology (S&T), in a country's economic growth and competitiveness. This chapter examines the downstream effects of these activities—their embodiment in the production of goods and services—on the performance of the United States and other major economies in the global marketplace.

This chapter covers three main areas. The first is knowledge- and technology-intensive (KTI) industries; the second is trade in KTI products and services; and the third is sustainable energy research and technologies.

KTI industries encompass both service and manufacturing sectors, based on 15 categories of industries formerly classified by the Organisation for Economic Co-operation and Development (OECD 2001, 2007) that have a particularly strong link to S&T (Table 6-1).[1] These include five knowledge-intensive services industries, five high-technology manufacturing industries, and five medium-high-technology industries. The definition of KTI industries has been expanded with the addition of medium-high-technology manufacturing industries for this 2018 edition of *Science and Engineering Indicators* (see sidebar New Definition of KTI Industries). In prior editions KTI consisted of 10 categories of industries—five knowledge-intensive (KI) services industries and five high-technology manufacturing industries.

- Five KI services industries incorporate high technology either in their services or in the delivery of their services. Three of these—financial, business, and information services (including computer software and R&D)—are generally commercially traded. The others—education and health care—are publicly regulated or provided and remain relatively more location bound (Table 6-1). Although they are far less market driven than other KTI industries in the global marketplace, competition in education and health appears to be increasing. Public KI services are also becoming more global; for example, many universities have international campuses.
- Five high-technology manufacturing industries spend a large proportion of their revenues on R&D and make products that contain or embody technologies developed from R&D (Table 6-1). These are aircraft and spacecraft; pharmaceuticals; computers and office machinery; semiconductors and communications equipment (treated separately in the text); and measuring, medical, navigation, optical, and testing instruments.[2] Aircraft and spacecraft and

pharmaceuticals are less market driven than the other three industries because of public funding, procurement, and regulation.[3]

- Five medium-high-technology manufacturing industries spend a relatively large proportion of their revenues on R&D (▦ Table 6-1). These are motor vehicles and parts, chemicals excluding pharmaceuticals, electrical machinery and appliances, machinery and equipment, and railroad and other transportation equipment. Although they spend a relatively lower proportion of their revenue on R&D compared to high-technology manufacturing industries, medium-high-technology manufacturing industries produce many products that incorporate advanced and science-based technologies. For example, cars and trucks contain sophisticated sensors and software to prevent accidents, optimize engine performance, and maximize fuel economy.

TABLE 6-1

Knowledge- and technology-intensive industries, by category

(KTI industries and categories)

Category	Industry
Public KI services	Education
	Primary education
	Secondary education
	Higher education
	Adult education
	Health care
	Counseling
	Hospitals
	Medical and dental practices
	Veterinary
Commercial KI services	Business
	Advertising
	Architectural, engineering, and other technical activities
	Building maintenance and support
	Data processing
	Leasing
	Legal, accounting, and auditing activities
	Market research and public opinion polling
	R&D services
	Financial
	Banking and finance
	Pension
	Insurance
	Commodity, securities, and stock markets
	Information

Category	Industry
	Broadband transmission
	Cable broadcasting
	Cellular transmission
	Computer programming, consultancy and related activities
	Film and video
	Internet
	Software
	Telephone (landline)
	TV broadcasting
High-technology manufacturing	Aircraft and spacecraft
	Communications and semiconductors
	Computers and office machinery
	Pharmaceuticals
	Measuring, medical, navigation, optical, and testing equipment
Medium-high-technology manufacturing	Motor vehicles and parts
	Chemicals excluding pharmaceuticals
	Electrical machinery and appliances
	Machinery and equipment
	Railroad and other transportation equipment

KI = knowledge intensive; KTI = knowledge and technology intensive.

Source(s)

United Nations Statistics Division, International Standard Industrial Classification (ISIC) of All Economic Activities, Rev.3, https://unstats.un.org/UNSD/cr/registry/regcst.asp?Cl=2, accessed 15 August 2017.

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Non-KTI industries are also very important in the world economy and therefore receive some attention in this chapter.

The globalization of the world economy involves the rise of new centers of KTI industries.[4] Advances in S&T have enabled companies to spread KTI activity to more locations around the globe and to develop strong interconnections among geographically distant entities. Although the United States and the European Union (EU) continue to be leading global producers in many of these industries, China has become the global leader in many technology-intensive manufacturing industries and is moving from final assembly into higher-value activities, including R&D and manufacture of sophisticated products. Overall, the United States is the largest global producer of high-technology manufacturing industries. However, China is the largest global producer in the information and communication technologies (ICT) manufacturing industries. China is the world's largest global producer in medium-high-technology industries. The U.S. and the EU lead in the production of commercial knowledge-intensive services; China is growing rapidly and is now the third largest producer.

This chapter ends with a discussion of global investment in sustainable energy research and technologies. In recent years, developed and emerging economies have invested in developing improved technologies for generating sustainable energy. Energy has a strong link to S&T and, like ICT, is a key element of infrastructure.

Several themes cross-cut the various indicators examined in the chapter:

- The United States has had robust growth in many KTI industries and trade of KTI goods and services following the global recession, in contrast to tepid or negative growth by the EU and Japan. The United States continues to be the world's largest provider of commercial KI services. China has continued to grow faster than developed countries in many KTI industries and has become the world's largest producer in many technology-intensive manufacturing industries. Although its share is lower in commercial KI services, China is growing far more rapidly overall than developed countries.
- The high-technology and medium-high-technology manufacturing industries are the most globalized among the KTI industries. Two high-technology manufacturing industries—communications and semiconductors and computers—have complex global value chains where manufacturing is located far away from the final markets. Although production is globalized in motor vehicles and parts, a medium-high-technology industry, manufacturing generally occurs near or in the final markets.
- Developed countries continue to dominate in KTI industries despite much more rapid growth by China. Developed countries account for nearly 70% of global production of commercial knowledge-intensive services industries, which are the largest category of KTI industries. However, China is the world's second largest producer in high-technology manufacturing industries, and is the largest producer in medium-high-technology industries.
- Globalization is increasing rapidly in the much larger commercial knowledge-intensive services industries but remains generally lower than in high-technology or medium-high-technology manufacturing. Business services is highly globalized with firms contracting out these services to providers located in developed and developing countries.
- China plays a unique role in global KTI industry production. China's global share in several high-technology- and medium-high-technology industries is comparable with or exceeds that of the United States or the EU.
- Among the KTI industries in developed countries, those in the United States have grown the strongest since the global recession. Growth of KTI industries in the EU and Japan has been weaker than the United States.

Chapter Organization

This chapter focuses on the major players in the global KTI arena, namely the United States, the EU, Japan, China, and other Asian economies. Other major developing countries, including Brazil, India, Indonesia, and Russia, also receive some attention. The time span is from the early 2000s to the present.

This chapter is organized into three sections:

- The first section discusses the prominent role of KTI industries in regional and national economies around the world, describes the global spread of KTI industries, and analyzes regional and national shares of worldwide production. It discusses shares for the KTI industry group as a whole and the knowledge-intensive services and high-technology manufacturing groups. Because advanced technology is increasingly essential for non-high-technology industries, some data on these industries are also presented.

- The second section discusses indicators of increased interconnection of KTI industries in the global economy. It examines patterns and trends in global trade in KTI products and services, with a focus on the links among the United States, the EU, Japan, China, and other Asian countries.
- The last section presents data on sustainable energy research and technologies, which have become a policy focus in many developed and developing nations. These energy technologies, like KTI industries, are closely linked to R&D. Production, investment, and innovation in these energies and technologies are rapidly growing in the United States and other major economies.
- Prior editions of this chapter contained a section on innovation-related indicators, which covered innovation activities of U.S. companies, patenting by the United States and other major economies by technology area, trade in royalties and fees, and venture capital and Small Business Innovation Research investment. For the 2018 edition of *Science and Engineering Indicators*, a new chapter—Chapter 8, Invention, Knowledge Transfer, and Innovation—integrates and extends the innovation-related indicators that have previously been presented in Chapters 4, 5, and 6 of prior editions of *Science and Engineering Indicators*. This new chapter presents a more holistic and comprehensive approach to coverage of innovation and related activities.

Data Sources, Definitions, and Methodology

This chapter uses a variety of data sources. Although several are thematically related, they have different classification systems (see sidebar Industry Data and Terminology. The discussion of regional and country patterns and trends includes an examination of developed and developing countries using the International Monetary Fund's categorization. Countries classified by the International Monetary Fund as advanced are developed countries, whereas those classified as emerging and developing are considered to be developing.

SIDEBAR

Industry Data and Terminology

The data and indicators reported here permit the tracing and analysis of broad patterns and trends that shed light on the spread and shifting distribution of global knowledge- and technology-intensive (KTI) capabilities. The industry data used in this chapter are derived from a proprietary IHS Global Insight database that assembles data from the United Nations (UN) and the Organisation for Economic Co-operation and Development to cover 70 countries consistently. IHS estimates some industry data for developing countries, including China, that are missing or not available on a timely basis.

Firms are classified by their primary activity in the UN's International Standard Industrial Classification of All Economic Activities. Thus, a company that primarily manufactures pharmaceuticals, for example, but also operates a retail business would have all its economic activity counted under pharmaceuticals. ▦ Table 6-A describes these classification systems and aims to clarify the differences among them.

Production is measured as value added. Value added is the amount contributed by an economic entity—country, industry, or firm—to the value of a good or service. It excludes purchases of domestic and imported supplies as well as inputs from other countries, industries, or firms.

Value added is measured in current dollars. For countries outside the United States, value added is recorded in the local currency and converted at the prevailing nominal exchange rate. Industry data are reported in current dollar terms because most KTI industries are globally traded and because most international trade and foreign direct investment is dollar denominated. However, current dollars have shortcomings as a measure of economic performance, which the reader should bear in mind. Economic research has found a weak link between nominal exchange rates of countries' currencies that are globally traded and differences in their economic performance (Balke, Ma, and Wohar 2013). In addition, the exchange rates of some countries' currencies are not market determined.

Using value added as a measure of output has disadvantages. It is credited to countries or regions based on the reported location of the activity, which is often uncertain because of companies' use of different reporting and accounting conventions. In addition, the value added of companies that have diversified businesses is assigned to the single industry that accounts for the largest share of the company's business. Moreover, a company classified as manufacturing may include services, and vice versa. For China and other developing countries, industry data may be estimated by IHS Global Insight or may be revised frequently because of rapid economic change or improvements in data collection by national statistical offices.

For all these reasons, the reader should view the value-added trends analyzed here as relatively internally consistent but broad indicators of the changing geographical distribution where economic value is generated. Small differences and fluctuations in the data should be treated with caution.

TABLE 6-A

Data Sources

(Topics and selected data source information)

Topic	Data provider	Variables	Basis of classification	Coverage	Methodology
Knowledge-intensive (KI) services and high-technology (HT) manufacturing industries	IHS Global Insight, World Industry Service database (proprietary)	Production, value added	Industry basis using International Standard Industrial Classification of All Economic Activities	KI services — business, financial, information, health, and education	Uses data from national statistical offices in developed countries and some developing countries and estimates by IHS Global Insight for some developing countries
Information and communications technologies (ICT) spending	IHS Global Insight, Global ICT Navigator (proprietary database)	ICT expenditures, by businesses and consumers	ICT consumer spending of population, by country	Not applicable	Uses data from national statistical offices and other sources and estimates by IHS Global Insight for some developing countries
Trade in commercial KI services	World Trade Organization	Exports and imports	Product basis using Extended Balance of Payments Services classification	KI services — business, financial, information, and royalties and fees	Uses data from national statistical offices, the International Monetary Fund, and other sources
Trade in HT goods	IHS Global Insight, World Trade Service database (proprietary)	Exports and imports	Product basis using Standard International Trade Classification	Aerospace, pharmaceuticals, office and computing equipment, communications equipment, and scientific and measuring instruments	Uses data from national statistical offices and estimates by IHS Global Insight
Globalization of U.S. multinationals	U.S. Bureau of Economic Analysis (BEA)	Value added, employment, and inward and outward direct investment	Industry basis using North American Industrial Classification System (NAICS)	Commercial KI services — business, financial, and information	BEA annual surveys of U.S. multinationals and U.S. subsidiaries of non-U.S. multinationals

Topic	Data provider	Variables	Basis of classification	Coverage	Methodology
U.S. industry innovation activities	National Science Foundation, Business R&D and Innovation Survey	Innovation activities	U.S. businesses with more than five employees	Industries classified on an industry basis using NAICS	Survey of U.S.-based businesses with more than five employees using a nationally representative sample
U.S. Patent and Trademark Office (USPTO) patents	Science-Metrix, SRI International, Scopus, LexisNexis	Patent grants	Inventor country of origin, technology area as classified by the Patent Board	More than 400 U.S. patent classes, inventors classified according to country of origin and technology codes assigned to the grant	Source of data is USPTO
Triadic patent families	Organisation for Economic Co-operation and Development (OECD)	Patent applications	Inventor country of origin and selected technology area as classified by the OECD	Broad technology areas as defined by the OECD, inventors classified according to country of origin	Sources of data are USPTO, European Patent Office, and Japan Patent Office
Venture capital	Dow Jones VentureSource	Investment, technology area, country of investor origin	Technology areas as classified by the Dow Jones classification system	Twenty-seven technology areas, investment classified by venture firms' country location	Data collected by analysts from public and private sources, such as public announcements of venture capital investment deals
Sustainable energy investment	Bloomberg New Energy Finance (BNEF)	Investment, technology area, country	Technology area classified by BNEF	Ten technology areas, investment classified by country receiving investment	Data collected by analysts from public and private sources, such as public announcements of venture capital investment deals
Public research, development, and demonstration (RD&D) in sustainable energy and related technologies	International Energy Agency (IEA)	Type of RD&D, technology area, country	Technology area classified by IEA	Six broad technology areas and numerous subtechnology areas	Data collected by IEA survey of its member countries

Topic	Data provider	Variables	Basis of classification	Coverage	Methodology
Public and private investment in energy infrastructure	IEA	Investment, type of energy source	Energy source classified by IEA	Six broad and numerous fine technology areas	Data collected by IEA survey of its member countries

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[1] See OECD (2001) for a discussion of classifying economic activities according to their degree of "knowledge intensity." Like all classification schemes, the OECD classification has shortcomings. For example, KTI industries produce some goods or services that are neither knowledge intensive nor technologically advanced. In addition, multiproduct companies that produce a mix of goods and services, only some of which are KTI, are assigned to their largest business segment. Nevertheless, data based on the OECD classification allow researchers and analysts to trace, in broad outline, worldwide trends toward greater interdependence in science and technology and the development of KTI sectors in many of the world's economies.

[2] In designating these high-technology manufacturing industries, the OECD estimated the degree to which different industries used R&D expenditures made directly by firms in these industries and R&D embedded in purchased inputs (indirect R&D) for 13 countries: the United States, Japan, Germany, France, the United Kingdom, Canada, Italy, Spain, Sweden, Denmark, Finland, Norway, and Ireland. Direct R&D intensities were calculated as the ratio of total R&D expenditure to output (production) in 22 industrial sectors. Each sector was weighted according to its share of the total output among the 13 countries, using purchasing power parities as exchange rates. Indirect intensities were calculated using the technical coefficients of industries on the basis of input-output matrices. The OECD then assumed that, for a given type of input and for all groups of products, the proportions of R&D expenditure embodied in value added remained constant. The input-output coefficients were then multiplied by the direct R&D intensities. For further details concerning the methodology used, see OECD (2001). It should be noted that several nonmanufacturing industries have R&D intensities equal to or greater than those of industries designated by the OECD as high-technology manufacturing. For additional perspectives on the OECD's methodology, see Godin (2004).

[3] Aircraft and spacecraft trends are affected by public funding for military aircraft, missiles, and spacecraft, and by different national flight regulations. Public funding and regulation of drug approval, prices, patent protection, and importation of foreign pharmaceuticals can affect pharmaceuticals.

[4] See Mudambi (2008) and Reynolds (2010) for a discussion of the shift to knowledge-based production and geographical dispersion of economic activity.

Patterns and Trends of Knowledge- and Technology-Intensive Industries

This section will examine the importance of KTI industries in the global economy as measured by the KTI share of gross domestic product (GDP) in the global and major economies, and the positions of the United States and other major economies in KTI industries, as measured by their value-added output and shares of global KTI activity (Appendix Table 6-1). (For an explanation of KTI industries, please see section Chapter Overview.)

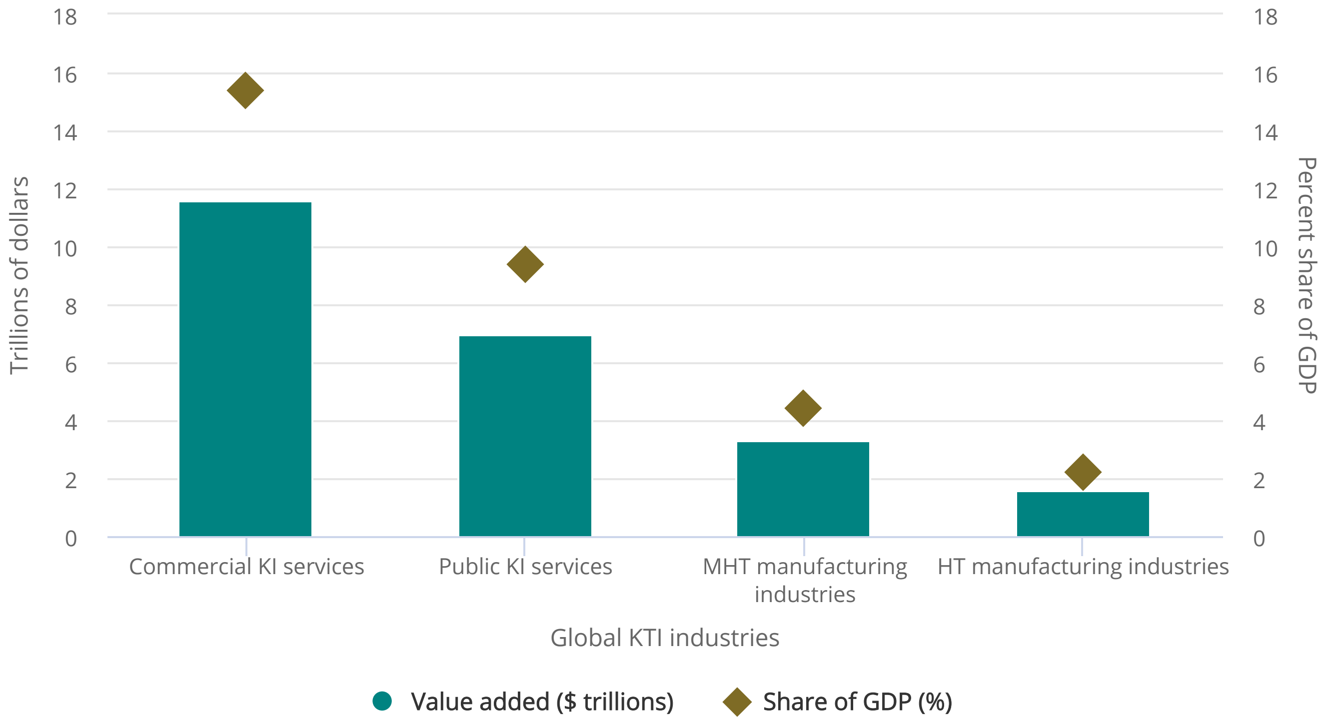
Knowledge- and Technology-Intensive Industries in the Global Economy

KTI industries have a value-added output of $24 trillion, making up nearly one-third of world GDP (📊Figure 6-1; Appendix Table 6-1, Appendix Table 6-2, and Appendix Table 6-3). This 2018 edition of *Science and Engineering Indicators* includes an expanded definition of KTI industries to add several industries with a value-added output of $3.3 trillion (see sidebar 💬New Definition of KTI Industries).

Among the KTI industries, the commercial knowledge-intensive services—business, financial, and information—have the highest share (15% of GDP) (📊Figure 6-1; ▦Table 6-1; Appendix Table 6-3 and Appendix Table 6-4). The public knowledge-intensive services—education and health care—have the second largest (9% of GDP) (📊Figure 6-1; Appendix Table 6-3, Appendix Table 6-5, and Appendix Table 6-6).[1] The newly added KTI industries for the 2018 edition of *Science and Technology Indicators* are medium-high-technology manufacturing industries that consist of motor vehicles and parts, electrical machinery, machinery and equipment, chemicals excluding pharmaceuticals, and railroad and other transportation equipment (see sidebar 💬New Definition of KTI Industries). These industries have the third largest share (4% of GDP) (📊Figure 6-1; Appendix Table 6-3 and Appendix Table 6-7). The high-technology manufacturing industries—aircraft and spacecraft; communications; computers; pharmaceuticals; semiconductors; and testing, measuring, and control instruments—are smaller, with a 2% share, but use and embody cutting-edge technologies (📊Figure 6-1; Appendix Table 6-3 and Appendix Table 6-8).

FIGURE 6-1

Global KTI industries, by output and share of GDP: 2016



GDP = gross domestic product; HT = high technology; KI = knowledge intensive; KTI = knowledge and technology intensive; MHT = medium-high technology.

Note(s)

Output of KTI industries is on a value-added basis. Value added is the amount contributed by a country, firm, or other entity to the value of a good or service and excludes purchases of domestic and imported materials and inputs. KTI industries include KI services, HT manufacturing industries, and MHT manufacturing industries based on a former classification by the Organisation for Economic Co-operation and Development. KI services include business, financial, information, education, and health care. Commercial KI services include business, financial, and information. Public KI services include education and health care. HT manufacturing industries include aircraft and spacecraft; communications and semiconductors; computers; pharmaceuticals; and testing, measuring, and control instruments. MHT manufacturing industries include motor vehicles and parts, electrical machinery, machinery and equipment, chemicals excluding pharmaceuticals, and railroad and other transportation equipment.

Source(s)

IHS Global Insight, World Industry Service database (2016). See Appendix Table 6-3 through Appendix Table 6-8.

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SIDEBAR

New Definition of KTI Industries

Previous editions of this chapter defined knowledge- and technology-intensive (KTI) industries based on two categories of industries formerly classified by the Organisation for Economic Co-operation and Development (OECD). Five high-technology manufacturing industries—aircraft and spacecraft; pharmaceuticals; computers and office machinery; semiconductors and communications equipment; and measuring, medical, navigation, optical, and testing instruments—spend a high proportion of their revenues on research and development (▦ Table 6-1).[*] Five knowledge-intensive services industries—business, education, financial, health care, and information—incorporate high technology either in these services or in the delivery of these services (▦ Table 6-1).[†] While output data are based on industry categories, trade data are based on products and not industry categories. The National Center for Science and Engineering Statistics classifies trade of KTI products and services by selecting products and services that closely correspond to KTI industries.

Trade of KTI products and services was previously defined as three categories of knowledge-intensive services—telecommunications, computer, and information; finance; and other business—and six categories of high-technology goods—aerospace; communications; computers; pharmaceuticals; semiconductors; and testing, measuring, and control instruments.[‡]

For this 2018 edition of *Science and Engineering Indicators*, we have expanded our definition of KTI industries to include five medium-high-technology industries in addition to the existing two categories of KTI services and high-technology manufacturing industries (▦ Table 6-1). The five medium-high-technology industries are motor vehicles and parts, chemicals excluding pharmaceuticals, electrical machinery and appliances, machinery and equipment, and railroad and other transportation equipment. These industries as formerly classified by the OECD spend a relatively large proportion of their revenues on R&D and make products to incorporate advanced technologies.* Although they spend a lower proportion of their revenue on R&D compared to high-technology manufacturing industries, medium-high-technology manufacturing industries produce many products that incorporate advanced and science-based technologies. For example, cars and trucks contain sophisticated sensors and software using sensing, measurement, and information and communications technologies to prevent accidents, optimize engine performance, and maximize fuel economy.

Consequently, the definition of KTI products and services has been expanded to make trade data consistent with the new definition of KTI industries. Chemicals excluding pharmaceuticals, motor vehicles and parts, machinery and equipment, electrical machinery and appliances, and railroad and other transportation equipment have been added to the existing three categories of knowledge-intensive services and six categories of medium-high-technology goods.

[*] In designating these high-technology and medium-high technology manufacturing industries, the OECD estimated the degree to which different industries used R&D expenditures made directly by firms in these industries and R&D embedded in purchased inputs (indirect R&D) for 13 countries: the United States, Japan, Germany, France, the United Kingdom, Canada, Italy, Spain, Sweden, Denmark, Finland, Norway, and Ireland. Direct R&D intensities were calculated as the ratio of total R&D expenditure to output (production) in 22 industrial sectors. Each sector was weighted according to its share of the total output among the 13 countries, using purchasing power parities as exchange rates. Indirect intensities were calculated using the technical coefficients of industries on the basis of input-output matrices. The OECD then assumed that, for a given type of input and for all groups of products, the proportions of R&D expenditure

embodied in value added remained constant. The input-output coefficients were then multiplied by the direct R&D intensities. For further details concerning the methodology used, see OECD (2001) and Godin (2004).

† See OECD (2001) for a discussion of classifying economic activities according to their degree of "knowledge intensity." Like all classification schemes, the OECD classification has shortcomings. For example, KTI industries produce some goods or services that are neither knowledge intensive nor technologically advanced. In addition, multiproduct companies that produce a mix of goods and services, only some of which are KTI, are assigned to their largest business segment. Nevertheless, data based on the OECD classification allow researchers and analysts to trace, in broad outline, worldwide trends toward greater interdependence in science and technology and the development of KTI sectors in many of the world's economies.

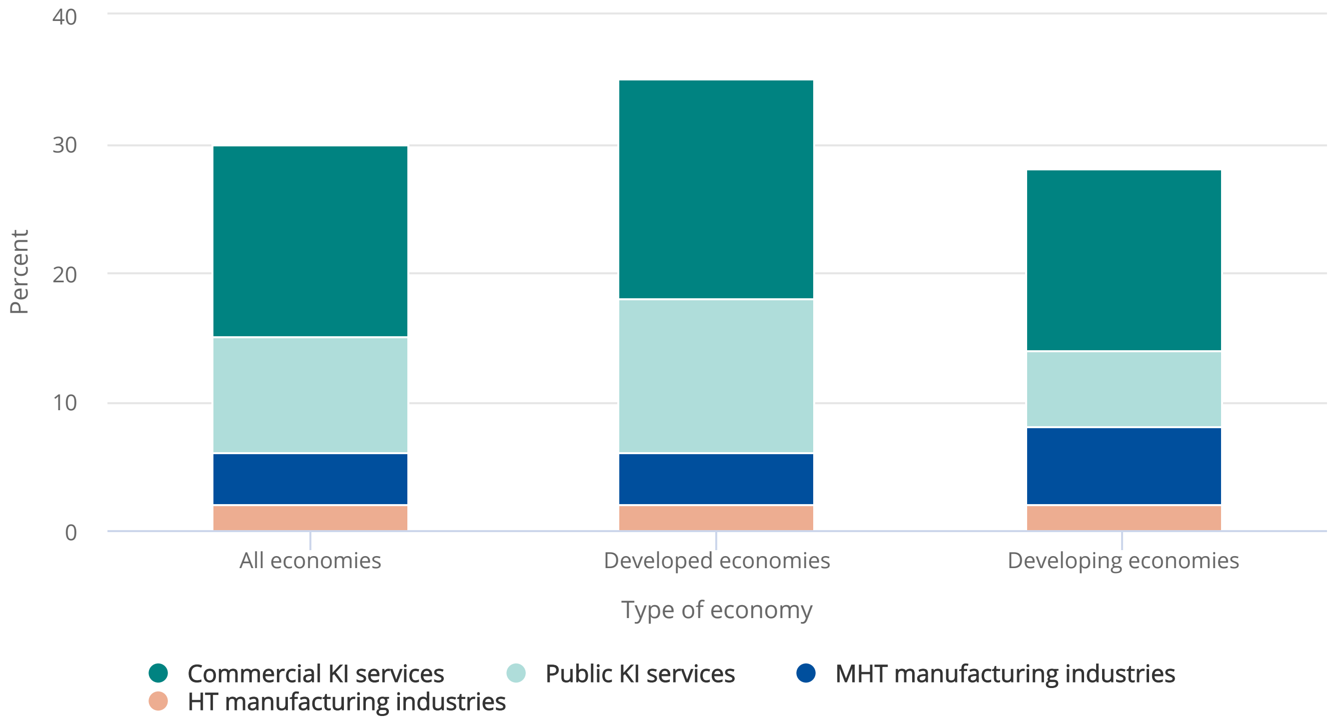
‡ Other business services include trade-related services, operational leasing (rentals), and miscellaneous business, professional, and technical services. These include legal, accounting, management consulting, public relations services, advertising, market research and public opinion polling, research and development services, architectural, engineering, and other technical services, agricultural, mining, and on-site processing (WTO 2016:83).

The KTI share of developed economies is higher than that of developing economies, largely because of their much higher share of knowledge-intensive services (Figure 6-2 and Figure 6-3; Appendix Table 6-2 through Appendix Table 6-6). But KTI shares vary widely, even among developed economies:

- The United States has the highest KTI share of any major developed economy (38%) largely because its share of commercial knowledge-intensive services is higher than the average for developed economies.
- The UK and Japan have the second highest share (36%). The United Kingdom (UK), like the United States, has a higher-than-average share of commercial KI services. In contrast, Japan has a much higher share in medium high-technology manufacturing industries compared to the United States and the UK. Germany also has a relatively high KTI share (35%) with a similar profile to Japan.

FIGURE 6-2

Selected industry category share of GDP of developed and developing economies: 2016



GDP = gross domestic product; HT = high technology; KI = knowledge intensive; MHT = medium-high technology.

Note(s)

Output of knowledge- and technology-intensive (KTI) industries is on a value-added basis. Value added is the amount contributed by a country, firm, or other entity to the value of a good or service and excludes purchases of domestic and imported materials and inputs. KTI industries include KI services, HT manufacturing industries, and MHT manufacturing industries based on a former classification by the Organisation for Economic Co-operation and Development. KI services include business, financial, information, education, and health care. Commercial KI services include business, financial, and information. Public KI services include education and health care. HT manufacturing industries include aircraft and spacecraft; communications and semiconductors; computers; pharmaceuticals; and testing, measuring, and control instruments. MHT manufacturing industries include motor vehicles and parts, electrical machinery, machinery and equipment, chemicals excluding pharmaceuticals, and railroad and other transportation equipment. Developed economies are those classified as advanced by the International Monetary Fund (IMF). Developing economies are those classified as emerging by IMF.

Source(s)

IHS Global Insight, World Industry Service database (2017). See Appendix Table 6-3 through Appendix Table 6-8.

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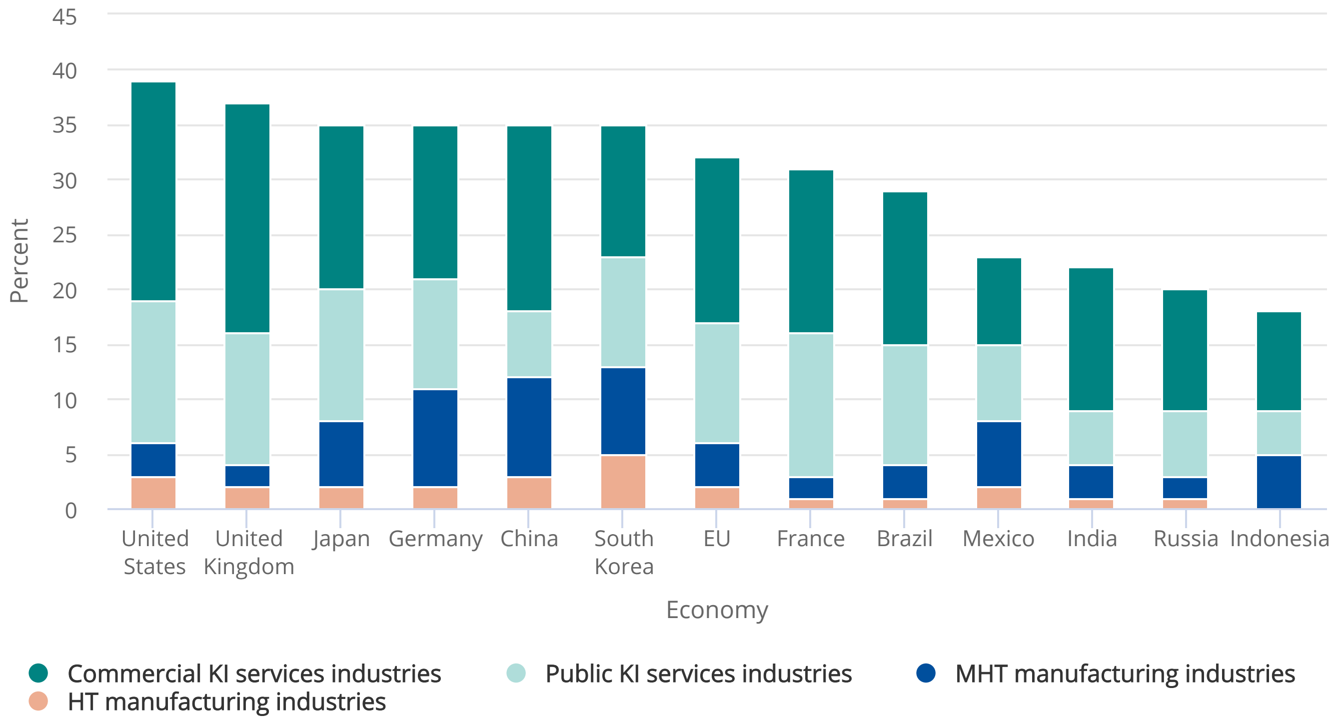
The KTI shares of large developing countries vary widely, in part reflecting differences in their stage of development, level of per capita income, and the size of their high-technology and medium-high-technology industries (📊Figure 6-3; Appendix Table 6-2 and Appendix Table 6-3).

- China has the largest share of any large developing economy (35%) due to its relatively large shares in medium-high-technology manufacturing industries and commercial KI services industries.
- Mexico, India, Russia, and Indonesia have KTI shares (19%–22%) that are considerably lower than the average for developing economies.

FIGURE 6-3

Output of KTI industries as a share of the GDP of selected countries or economies: 2016



EU = European Union; GDP = gross domestic product; HT = high technology; KI = knowledge intensive; KTI = knowledge and technology intensive; MHT = medium-high technology.

Note(s)

Data are not available for EU members Cyprus, Estonia, Latvia, Lithuania, Luxembourg, Malta, and Slovenia. China includes Hong Kong. Economies classified by the International Monetary Fund as *advanced* are developed countries, whereas those classified as *emerging* and *developing* are considered to be developing. Output of KTI industries is on a value-added basis. Value added is the amount contributed by a country, firm, or other entity to the value of a good or service and excludes purchases of domestic and imported materials and inputs. KTI industries include KI services, HT manufacturing industries, and MHT manufacturing industries based on a former classification by the Organisation for Economic Co-operation and Development. KI services include business, financial, information, education, and health care. Commercial KI services include business, financial, and information. Public KI services include education and health care. HT manufacturing industries include aircraft and spacecraft; communications and semiconductors; computers; pharmaceuticals; and testing, measuring, and control instruments. MHT manufacturing industries include motor vehicles and parts, electrical machinery, machinery and equipment, chemicals excluding pharmaceuticals, and railroad and other transportation equipment.

Source(s)

IHS Global Insight, World Industry Service database (2017). See Appendix Table 6-3 through Appendix Table 6-8.

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ICT Investment in Knowledge- and Technology-Intensive and Other Industries

Investment in ICT plays an important role in the competitiveness and innovation capability of KTI and other industries. In addition, the ICT industries (a subset of KTI industries), consisting of communications, semiconductors, and computers and information services, produce ICT products and services that are used by the entire economy. Many economists regard ICT as a general-purpose platform technology that fundamentally changes how and where economic activity is carried out in today's knowledge-based countries, much as earlier general-purpose technologies (e.g., the steam engine, automatic machinery) propelled growth during the Industrial Revolution.[2] Many KTI and other industries invest heavily in ICT to be successful and compete in global markets. Investment in ICT, particularly by businesses, is also important because it has a substantial impact on a country's living standards, employment, and productivity. The Internet of Things—ICT technologies that sense, measure, and connect devices through the Internet—is rapidly growing and holds the potential to raise consumer and business productivity and raise living standards (see sidebar 💬 The Internet of Things).[3]

SIDEBAR

The Internet of Things

The Internet of Things (IoT) has received growing attention by researchers, government, and businesses over the last several years. There are numerous and varying definitions of the IoT. For example, the United Nations defines it "as a global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies" (UN Broadband Commission for Sustainable Development 2016:12). The McKinsey Global Institute defines the IoT as "sensors or actuators embedded in physical objects that are linked through wired and wireless networks" (Manyika et al. 2015:17).

Numerous researchers and organizations believe that the IoT is rapidly growing and is already used in a wide variety of products and applications. For example, the Apple Watch monitors a user's activity, sleep time, and heart rate. The data generated from the Apple Watch is transmitted through the user's iPhone and fed to computers that analyze the data to provide feedback on health and fitness. In agriculture, precision farming equipment with wireless links to data collected from remote satellites and ground sensors measure crop conditions and adjust the way each individual part of a field is farmed.

The IoT is projected to have wide-ranging global economic and social impacts, including raising productivity, saving energy, improving health, automating chores and factory production, and optimizing mass-transportation and driverless cars. Manyika et al. (2015) projects that the economic impact of the IoT in 2025 will be equivalent to 4%–11% of global gross domestic product (GDP) Manyika et al. (2015:2). Furthermore, Manyika et al. (2015) projects that the industrial sector will be one of the largest sources of value from adoption of the IoT (1%–4% of GDP) due to improvements including automation of complex production processes, optimizing inventory, energy savings, and improving worker health and safety (Manyika et al. 2015:7).

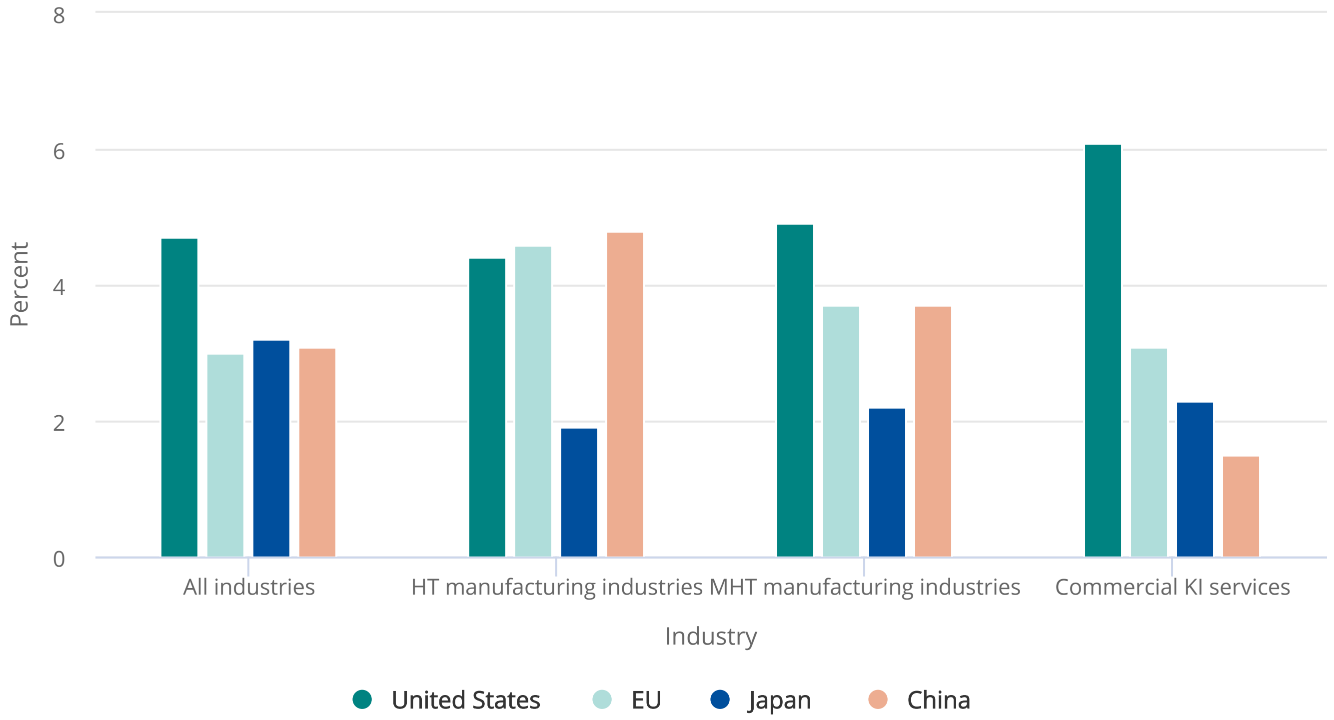
IHS Global Insight, a private economic research and consulting service, forecasts that global shipments of IoT devices will more than triple between 2017 and 2025 to reach 19.4 billion devices. The use of the number of shipments of IoT devices as an indicator has several limitations including the lack of an estimated market value for IoT devices, which vary widely in size and technological sophistication. For example, the value of an Apple Watch would be different from an IoT device used in a factory. In addition, IHS does not forecast objects that are currently unconnected, such as desk chairs and pet collars, which could be a very large part of the market.

According to IHS, the fastest growing sector will be industrial, jumping from 1.3 billion devices to 10.8 billion devices, pushing its share of all IoT devices from 21% to 56%. The rapid deployment of the IoT in this sector is broadly consistent with McKinsey Global's projection of a large economic impact on this sector. Although the number of devices will more than double from 2.1 billion to 4.9 billion, the consumer sector share will drop from 35% to 24%. Despite modest growth in communications devices, its share will drop sharply from 36% to 14%.

The United States has the highest rate of ICT investment in all of its industries (measured as an industry's ICT spending share of value-added output) compared to the other three largest economies—EU, Japan, and China (Figure 6-4). Among the KTI industries, the United States has a considerably higher rate of ICT investment in medium-high-technology manufacturing industries and commercial knowledge-intensive services. The high rate of ICT investment by U.S. commercial knowledge-intensive services coincides with the global dominance of this U.S. industry, particularly business services, a category that contains many advanced industries, such as R&D, architectural, and engineering services (Table 6-1). The rate of ICT investment for the other three economies is far below that of the United States in this industry. In high-technology manufacturing industries, China, the EU, and the United States have the same rate of ICT investment. Japan’s share is considerably lower.

FIGURE 6-4

ICT business spending as a share of selected industry categories for selected countries or economies: 2016



EU = European Union; HT = high technology; ICT = information and communications technology; KI = knowledge intensive; MHT = medium-high technology.

Note(s)

Data are not available for EU members Cyprus, Estonia, Latvia, Lithuania, Luxembourg, Malta, and Slovenia. China includes Hong Kong. Output of industries is on value-added basis. Value added is the amount contributed by a country, firm, or other entity to the value of a good or service and excludes purchases of domestic and imported materials and inputs. KTI industries include KI services, HT manufacturing industries, and MHT manufacturing industries based on a former classification by the Organisation for Economic Co-operation and Development. KI services include business, financial, information, education, and health care. Commercial KI services include business, financial, and information. Public KI services include education and health care. HT manufacturing industries include aircraft and spacecraft; communications and semiconductors; computers; pharmaceuticals; and testing, measuring, and control instruments. MHT manufacturing industries include motor vehicles and parts, electrical machinery, machinery and equipment, chemicals excluding pharmaceuticals, and railroad and other transportation equipment.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, IHS Global Insight ICT Global Navigator, accessed 14 August 2017.

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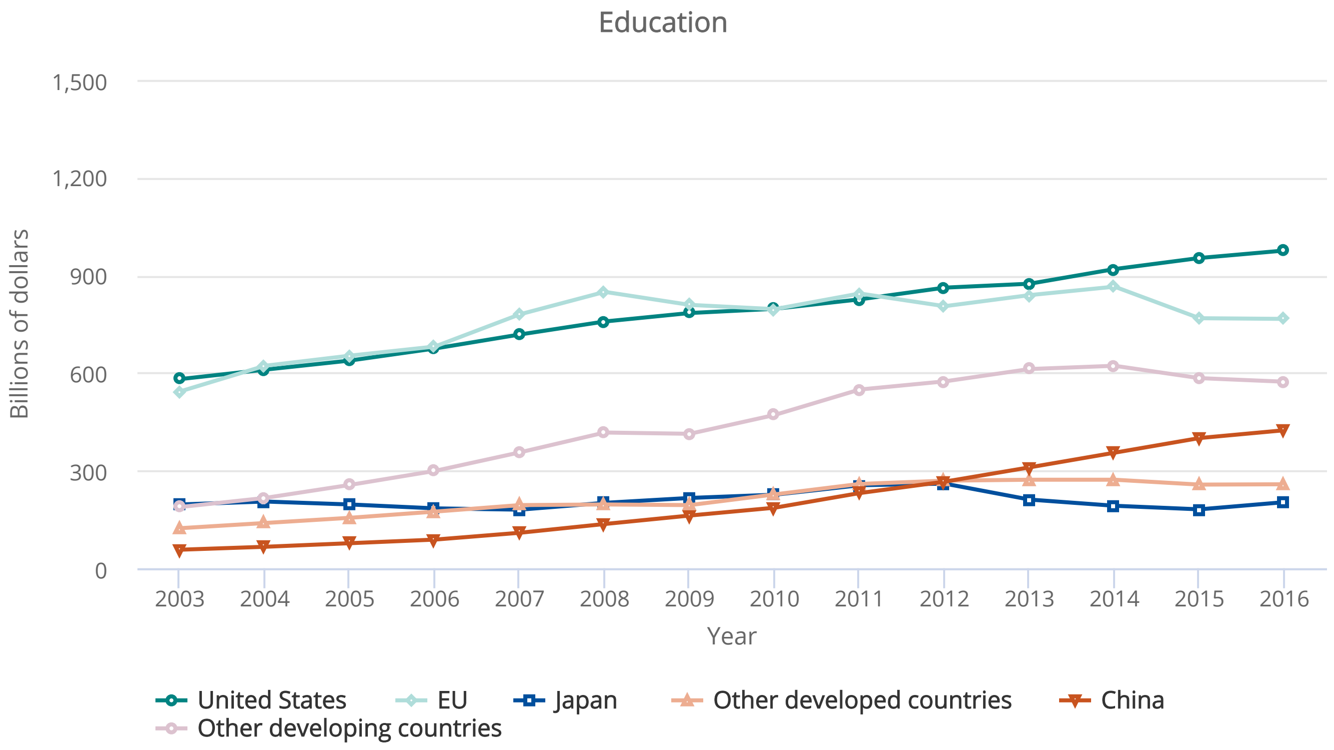
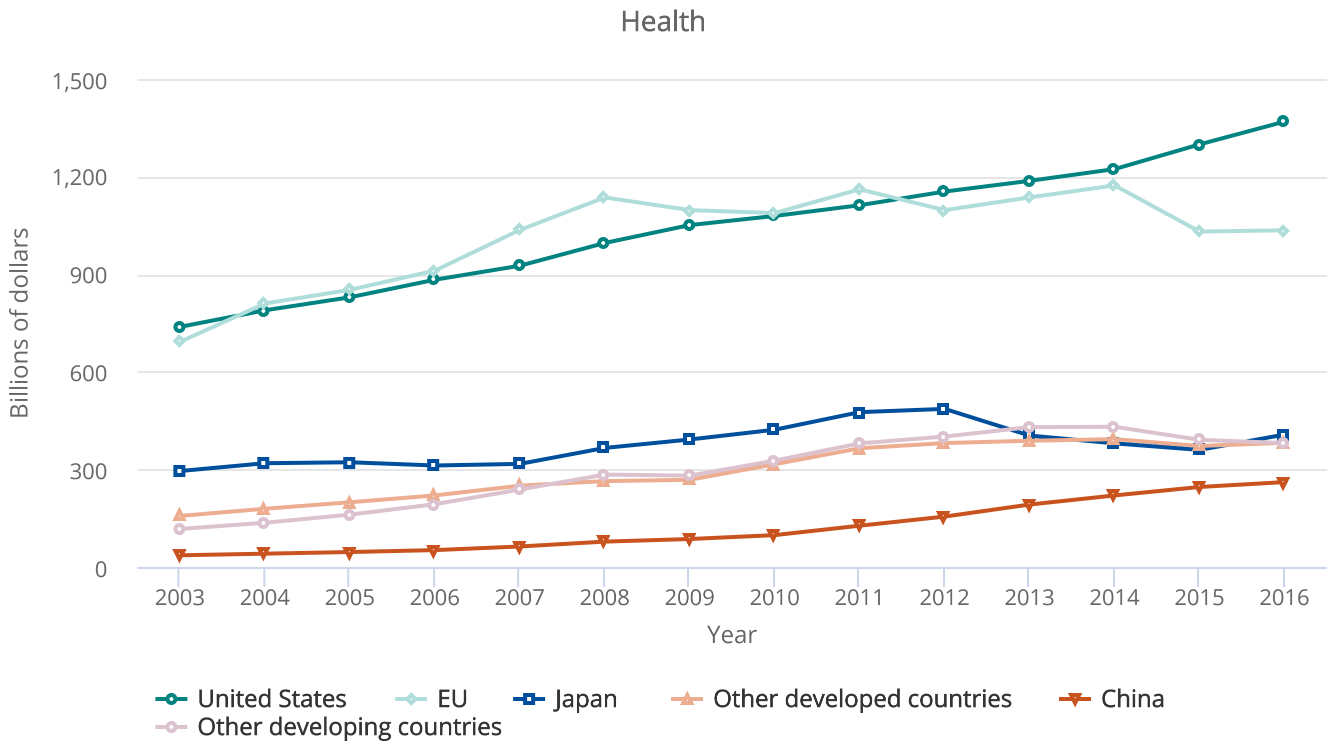
Global Trends in Public Knowledge-Intensive Services Industries

Public knowledge-intensive services—health care and education—account for $7 trillion in global value added (Figure 6-1 and Figure 6-5; Appendix Table 6-5 and Appendix Table 6-6). These sectors are major sources of knowledge and innovation of great benefit to national economies. Although they are far less market driven than other KTI industries in the global marketplace, competition in education and health appears to be increasing.[4] Education trains students for future work in science, technology, and other fields, and research universities are an important source of knowledge and innovation for other economic sectors. Many renowned universities are seeking to establish themselves as global brands. The health sector helps keep the population healthy and productive, trains and employs highly skilled workers, conducts research, and generates innovation. Leading medical centers in many countries are collaborating across borders, and "medical tourism," while modest, is growing.

FIGURE 6-5

Output of education and health care for selected regions, countries, or economies: 2003–16





EU = European Union.

Note(s)

Output of education and health is on a value-added basis. Healthcare includes social assistance. Value added is the amount contributed by a country, firm, or other entity to the value of a good or service and excludes purchases of domestic and imported materials and inputs. Data are not available for EU members Cyprus, Estonia, Latvia, Lithuania, Luxembourg, Malta, and Slovenia. China includes Hong Kong. Developed countries are those classified as advanced by the International Monetary Fund (IMF). Developing countries are those classified as emerging by IMF.

Source(s)

IHS Global Insight, World Industry Service database (2016). See Appendix Table 6-5 and Appendix Table 6-6.

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International comparison of both health care and education sectors is complicated by variations in the size and distribution of each country's population, market structure, and the degree of government involvement and regulation. Thus, differences in market-generated value added may not accurately reflect differences in the relative value of these services.

The United States and the EU are the world's largest providers of public and private education services, with global shares of 31% and 24%, respectively (Figure 6-5; Appendix Table 6-5). China is the third largest provider (13%), followed by Japan (6%). The United States and the EU are also the largest providers in health care (Appendix Table 6-6). Japan is the third largest provider followed by China.

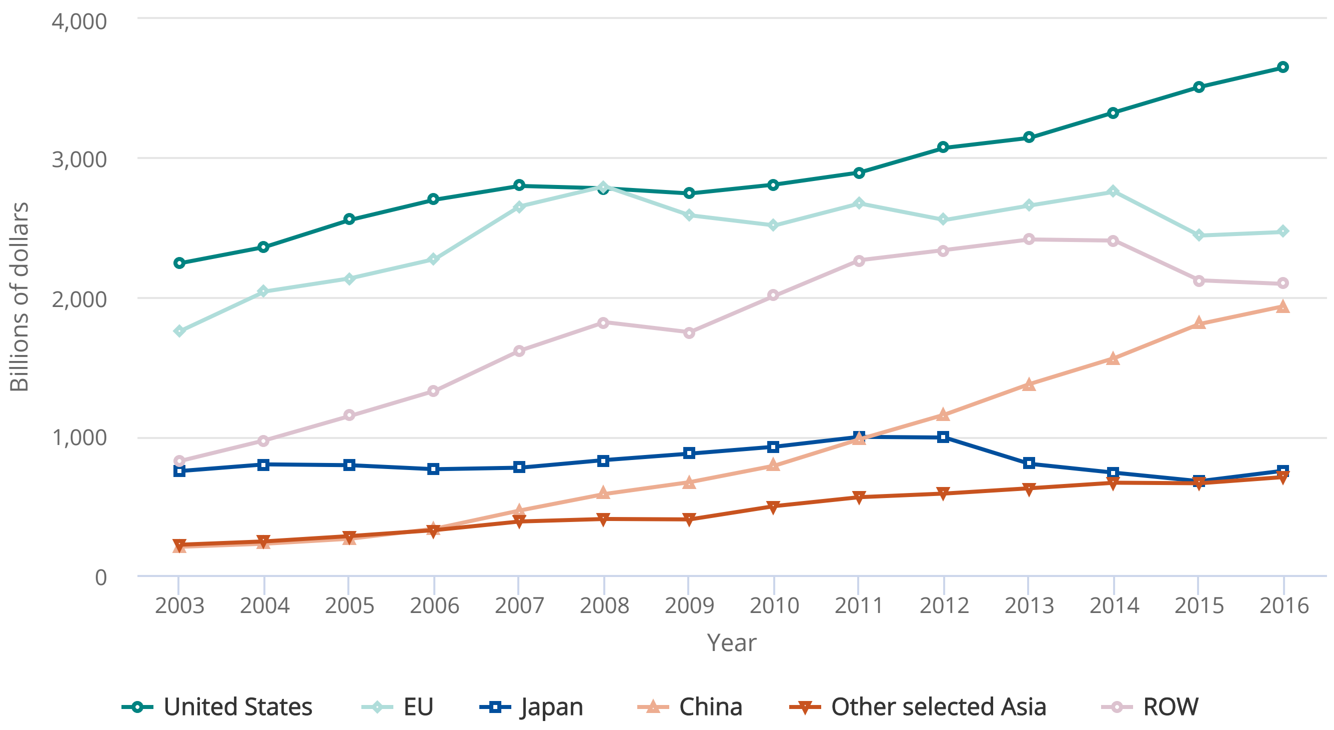
The U.S. global shares of education and health care remained roughly flat over the last decade despite rising in absolute value (Figure 6-5; Appendix Table 6-5 and Appendix Table 6-6). The shares of education and health care for the EU and Japan declined. China's global share of education and health care more than doubled during this period, in line with its rapid economic growth, emphasis on education, and focused efforts to improve the health care system. India and Indonesia also showed expansion. The growth of education in China and India coincided with increases in higher-education degree awards in both countries and, particularly, in doctorates in the natural science and engineering fields (see Chapter 2).

Global Trends in Commercial Knowledge-Intensive Services Industries

The global value added of commercial knowledge-intensive services—business, financial, and information—was $11.6 trillion in 2016 (Figure 6-1 and Figure 6-6; Appendix Table 6-4). Financial services is the largest industry within commercial KI services ($4.6 trillion) (Appendix Table 6-9). The large size of financial services reflects the wide and diverse activities of these industries, including banking, insurance, pension funding, leasing, commodities, securities, and stock markets. Business services, which include the technologically advanced industries of engineering, consulting, and R&D services, is the second largest industry ($4.0 trillion) (Appendix Table 6-10). Many businesses and other organizations purchase various services rather than provide them in-house, particularly in developing countries (Table 6-1). The third largest industry is information services that includes the technologically advanced industries of computer programming and information technology (IT) services ($3.1 trillion) (Appendix Table 6-11 and Appendix Table 6-12).

FIGURE 6-6

Output of commercial KI services for selected regions, countries, or economies: 2003–16



EU = European Union; KI = knowledge intensive; ROW = rest of world.

Note(s)

Output of commercial KI services is on a value-added basis. Value added is the amount contributed by a country, firm, or other entity to the value of a good or service and excludes purchases of domestic and imported materials and inputs. Commercial KI services are based on a former classification by the Organisation for Economic Co-operation and Development and include business, financial, and information services. Data are not available for EU members Cyprus, Estonia, Latvia, Lithuania, Luxembourg, Malta, and Slovenia. China includes Hong Kong. Other selected Asia includes India, Indonesia, Malaysia, Philippines, Singapore, South Korea, Taiwan, and Vietnam.

Source(s)

IHS Global Insight, World Industry Service database (2017). See Appendix Table 6-4.

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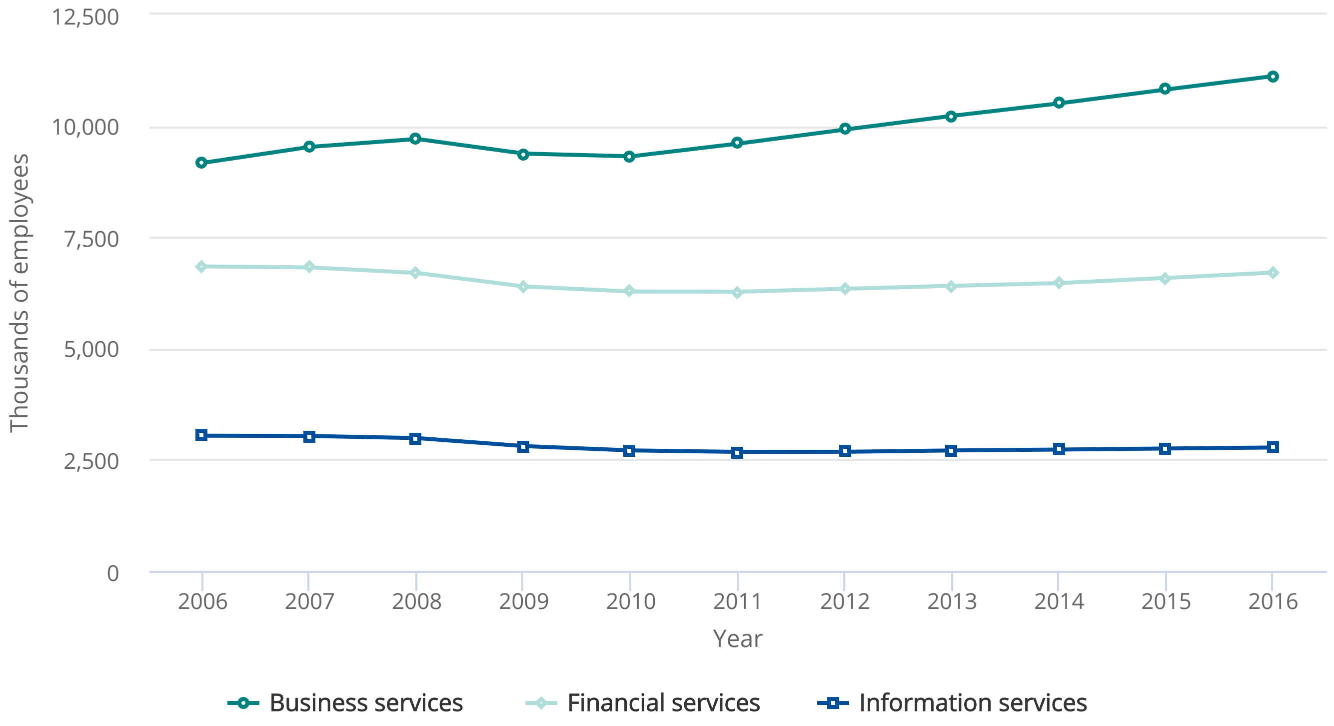
The United States accounted for 31% of global commercial knowledge-intensive services in 2016 (Figure 6-6; Appendix Table 6-4). U.S. commercial knowledge-intensive services industries employ 20.6 million workers, 17% of U.S. private sector employment (Figure 6-7). These industries perform 29% of U.S. industrial R&D, higher than their share of U.S. industrial output (Figure 6-8).

The EU is the second largest global provider (21% share) of commercial knowledge-intensive services (Figure 6-6; Appendix Table 6-4). China is third (17%), and Japan is fourth (6%).

FIGURE 6-7

U.S. employment in commercial KI services: 2006–16



KI = knowledge intensive.

Note(s)

KI services are classified by the Organisation for Economic Co-operation and Development. Commercial KI services include business, financial, and information services. Financial services include finance and insurance and rental and leasing. Business services include professional and technical services and management of companies and enterprises.

Source(s)

Bureau of Labor Statistics, Current Employment Statistics (2016), https://www.bls.gov/ces/, accessed 9 August 2017.

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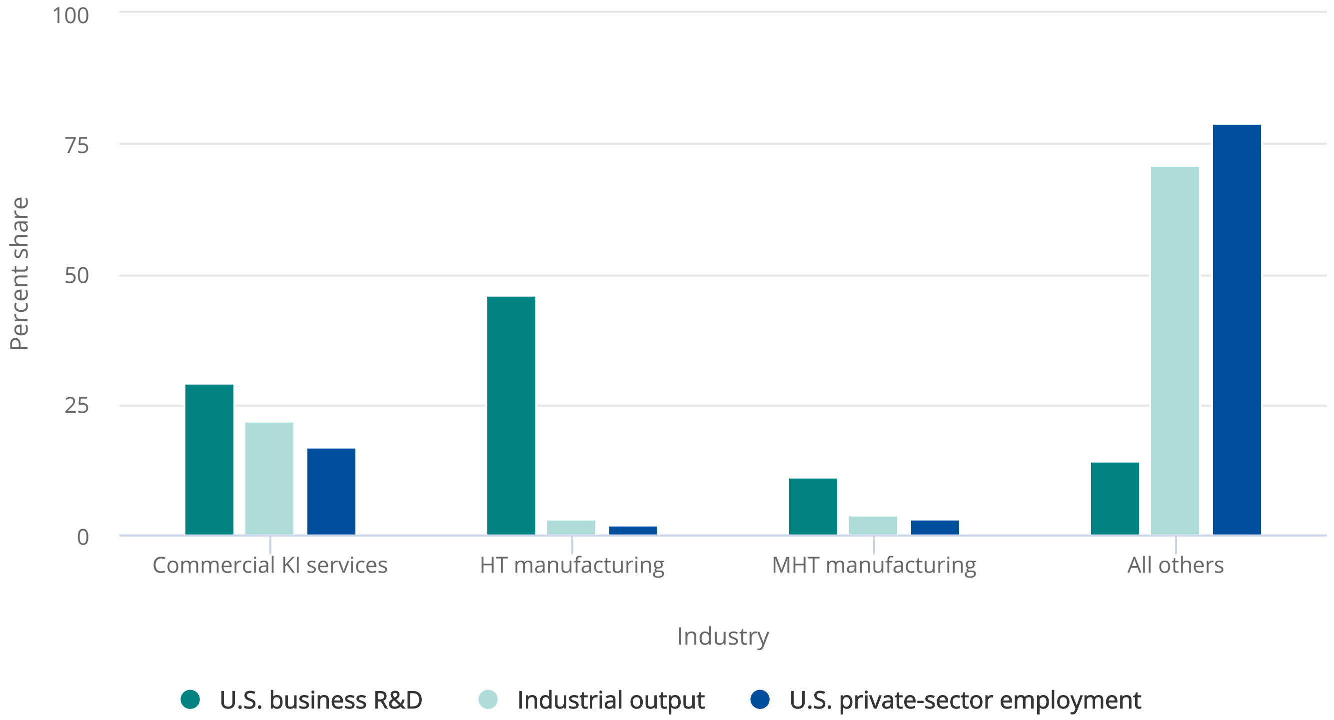
FIGURE 6-8

U.S. KTI industry share of U.S. business R&D spending, industry output, and industry employment: 2014



HT = high technology; KI = knowledge intensive; KTI = knowledge and technology intensive; MHT = medium-high technology.

Note(s)

Business R&D consists of domestic funding by companies' own internal funds and funds from other sources. HT and MHT manufacturing industries and KI services are formerly classified by the Organisation for Economic Co-operation and Development. HT manufacturing industries include aircraft and spacecraft; communications and semiconductors; computers; pharmaceuticals; and testing, measuring, and control instruments. MHT manufacturing industries include motor vehicles and parts, electrical machinery, machinery and equipment, chemicals excluding pharmaceuticals, and railroad and other transportation equipment. KI services include health, education, business, information, and financial services. Commercial KI services include business, information, and financial services. Business R&D of commercial KI services consists of professional and technical services and information. Coverage of some industries may vary among data sources because of differences in classification of industries.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Business R&D and Innovation Survey (BRDIS) (2014) https://www.nsf.gov/statistics/srvyindustry/.

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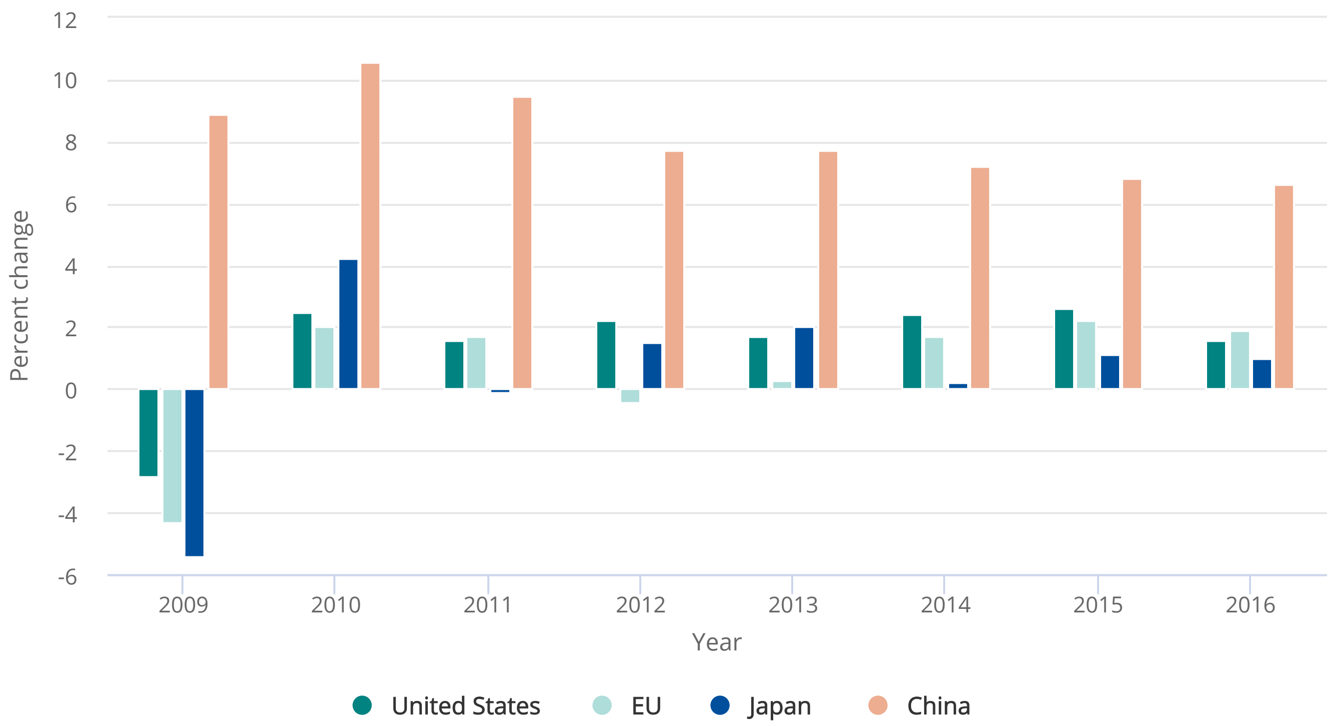
Commercial Knowledge-Intensive Services in the United States

During the post-global recession period of 2011 through 2016, the steady growth of U.S. commercial knowledge-intensive services between 2011 and 2016 contrasts with declines in the EU and Japan, which have had comparatively weaker economic recoveries (Figure 6-6 and Figure 6-9). U.S. value-added output of commercial knowledge-intensive services grew 26% higher during this period, driven by business and financial services (Appendix Table 6-9 and Appendix Table 6-10). However, China grew far faster than the United States with its output nearly doubling.

FIGURE 6-9

Growth in real GDP, by selected region, country, or economy: 2009–16



EU = European Union; GDP = gross domestic product.

Note(s)

GDP is in billions of dollars on 2010 purchasing power parity basis. China includes Hong Kong. The EU consists of 28 current member countries.

Source(s)

IHS Global Insight, Global Monthly Forecast Update, accessed 17 January 2017.

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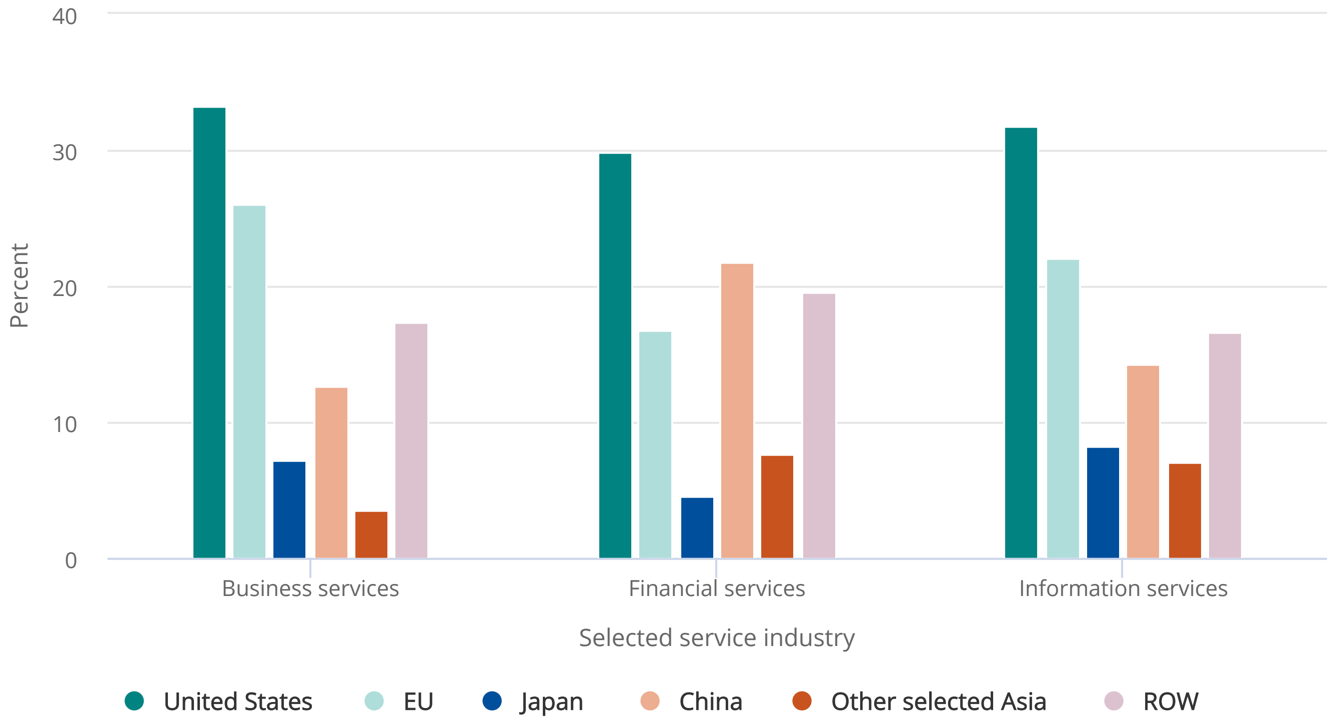
Since 2006, the U.S. global share of commercial knowledge-intensive services has slightly declined from 35% to 31% (Figure 6-6; Appendix Table 6-4). These changes have been largely due to much faster growth in China. However, the United States continues to be the dominant global provider of commercial knowledge-intensive services. The United States has a strong position in business services (33% global share), a category that includes advanced-technology industries such as engineering, architectural, and R&D services (Figure 6-10; Table 6-1). Business services led the growth of U.S. commercial knowledge-intensive industries over the last decade (Appendix Table 6-10). One source of growth of this U.S. industry has been the infrastructure boom in developing countries, which has employed U.S. firms in areas including architecture, engineering, and consulting.[5]

FIGURE 6-10

Global value-added shares of selected service industries for selected regions, countries, or economies: 2016



EU = European Union; ROW = rest of world.

Note(s)

Value added is the amount contributed by a country, firm, or other entity to the value of a good or service and excludes purchases of domestic and imported materials and inputs. Business services include computer programming, R&D, and other business services. Financial services include leasing. Data are not available for EU members Cyprus, Estonia, Latvia, Lithuania, Luxembourg, Malta, and Slovenia. China includes Hong Kong. Other selected Asia includes India, Indonesia, Malaysia, Philippines, Singapore, South Korea, Taiwan, and Vietnam.

Source(s)

IHS Global Insight, World Industry Service database (2017). See Appendix Table 6-7 through Appendix Table 6-13.

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Employment in U.S. commercial knowledge-intensive services has grown more slowly than value added output in the post-global recession period reaching 20.6 million in 2016, a gain of 2.0 million jobs over 2011 (Figure 6-7).[6] Business and financial services added about 1.5 million and 400,000 jobs, respectively. Employment in information services was stagnant.

The high growth in output of U.S. commercial knowledge-intensive services relative to weak job growth is consistent with historical trends and is largely explained by faster labor productivity growth in these industries relative to non-KTI industries (NSF/NCSES 2014:7).

Commercial Knowledge-Intensive Services in the EU

Output of commercial knowledge-intensive services in the EU fell 8% between 2011 and 2016 (Figure 6-6; Appendix Table 6-4). The slow pace of growth of commercial knowledge-intensive services coincides with the EU's weak and halting economic recovery (Figure 6-9). Over the last decade, the EU's global share has declined from 29% to 21% due to faster growth in the United States and China and other developing countries (Figure 6-6; Appendix Table 6-4). The EU's global share in business services slid from 34% to 26% during this period (Appendix Table 6-10). However, the EU continues to be the second largest global provider in this industry.

The substantial depreciation of the euro relative to the dollar in 2011–16 likely overstated the weakness of the EU's commercial knowledge-intensive services and other KTI industries (see sidebar Currency Exchange Rates of Major Economies).

Commercial Knowledge-Intensive Services in China

China's commercial KI services grew rapidly during the post-global recession period, with output nearly doubling between 2011 and 2016 (Figure 6-6; Appendix Table 6-4). However, toward the end of this period, growth of commercial KI services slowed in 2016, coinciding with the moderation in China's economic growth (Figure 6-9).

Over the last decade, commercial KI services in China has grown at an average annual rate of nearly 20%, resulting in its global share more than quadrupling to reach 17% (Appendix Table 6-4). China surpassed Japan in 2012 to become the world's third largest provider, with its global share in 2016 more than double the size of Japan's. Business services and financial services led the growth of China's commercial KI services (Appendix Table 6-9 and Appendix Table 6-10). China's industry that provides outsourced business services to firms based in other countries has grown rapidly over the last decade.[7]

Commercial Knowledge-Intensive Services in Japan

Output of Japan's commercial knowledge-intensive services shrank 24% in the post-global recession period (Figure 6-6; Appendix Table 6-4), and this trend has coincided with Japan's halting recovery from the global recession (Figure 6-9). In addition, Japan's global position in commercial knowledge-intensive services has weakened over the last decade coinciding with the lengthy stagnation of the Japanese economy (Figure 6-6; Appendix Table 6-3 and Appendix Table 6-4).

The substantial depreciation of the yen relative to the dollar in 2011–16 likely overstated the weakness of Japan's commercial knowledge-intensive services industries and other KTI industries (see sidebar Currency Exchange Rates of Major Economies).

Commercial Knowledge-Intensive Services in Other Countries

Trends were mixed in other large developing economies. India and Indonesia had sizeable gains in commercial knowledge-intensive services over the last decade, with their global shares reaching 3% and 1%, respectively (Appendix Table 6-3 and Appendix Table 6-4). In Brazil and Russia, output of commercial knowledge-intensive services industries was down sharply over the last decade due to their economies entering recession in 2014–16. India had strong gains in business and information services, reflecting, in part, the success of Indian firms providing IT, accounting, legal, and other services to developed countries (Appendix Table 6-10 and Appendix Table 6-11). Indonesia had strong gains in financial services and business services (Appendix Table 6-9 and Appendix Table 6-10).

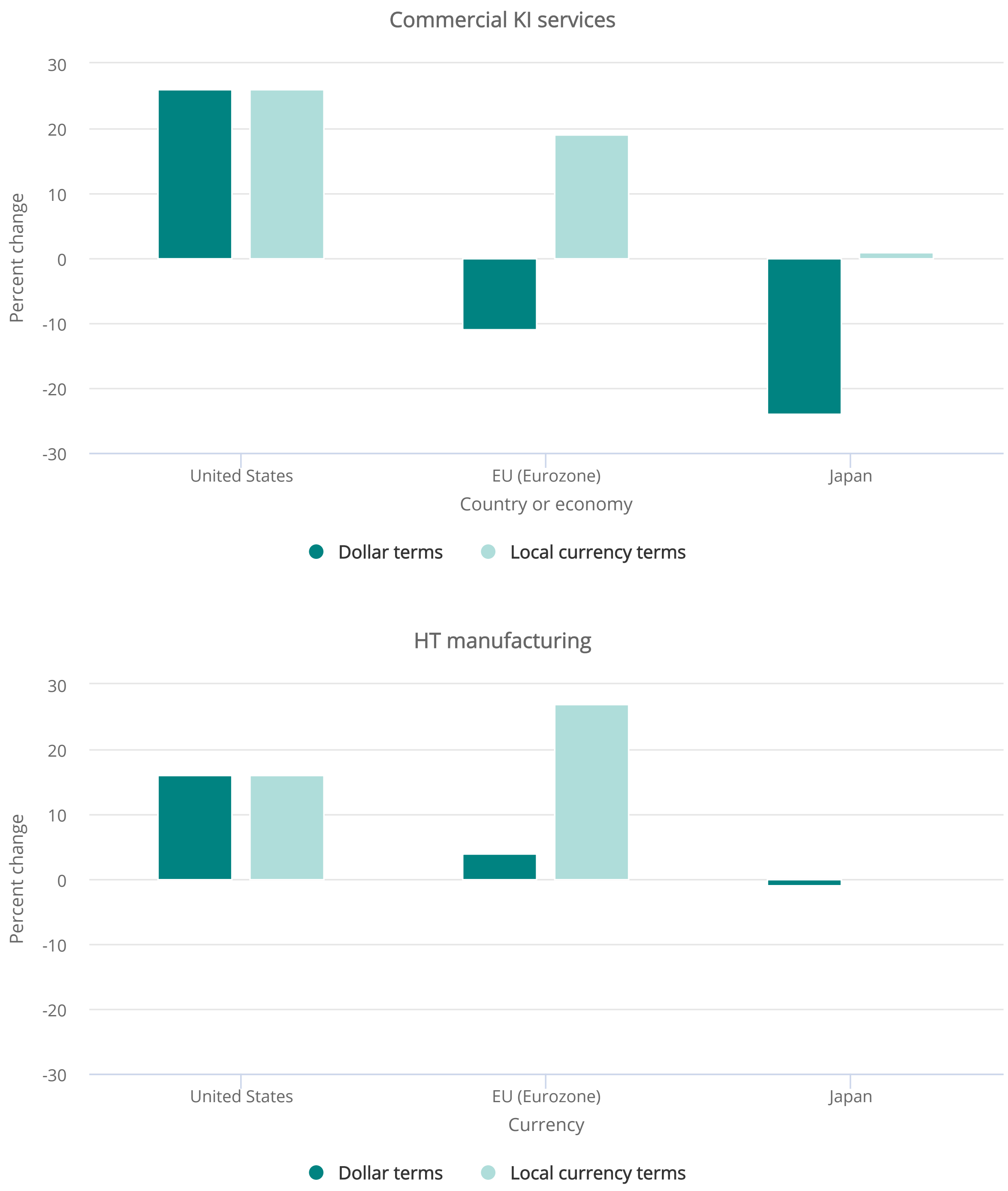
SIDEBAR

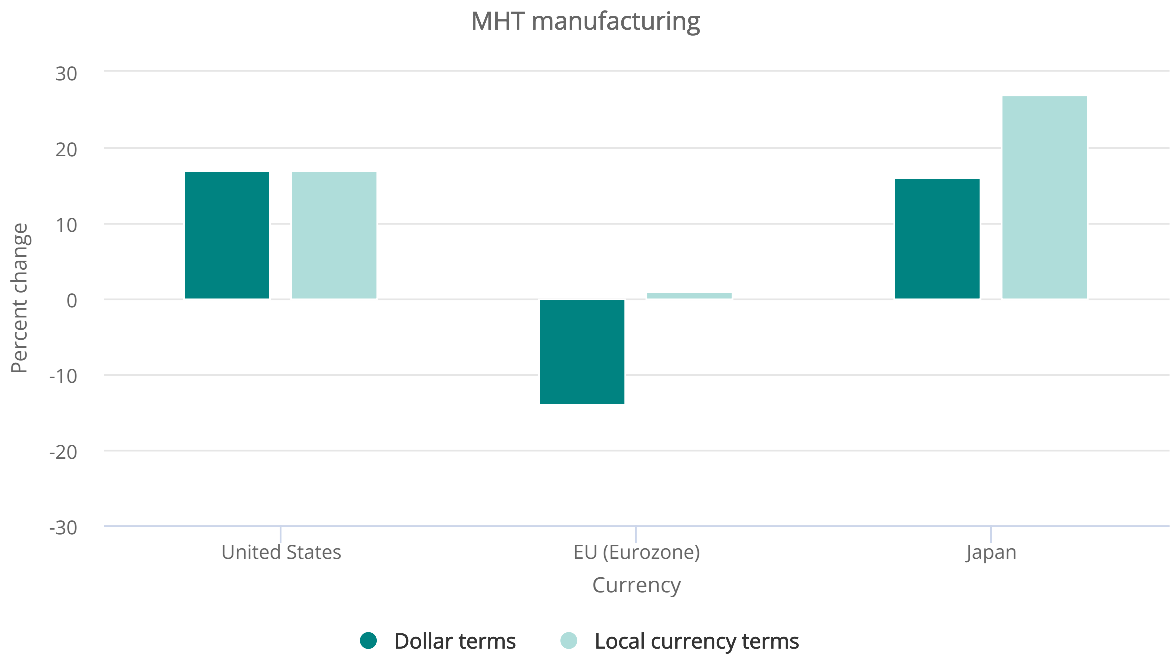
Currency Exchange Rates of Major Economies

The substantial depreciation of the euro and yen against the dollar from 2011 to 2016 reduced the value of the eurozone's and Japan's economic activities in dollar terms relative to their value in local currency terms. Economic activities such as GDP and industry output, denominated in local currencies, had a higher growth rate than these activities denominated in dollars (Figure 6-A).

FIGURE 6-A

Growth in output of selected categories of industries, by selected country or economy: 2011–16





EU = European Union; HT = high technology; KI = knowledge intensive; MHT = medium-high technology.

Note(s)

Output of HT manufacturing industries is on a value-added basis. Value added is the amount contributed by a country, firm, or other entity to the value of a good or service and excludes purchases of domestic and imported materials and inputs. HT manufacturing industries include aerospace; communications; computers; pharmaceuticals; semiconductors; and testing, measuring, and control instruments and are based on a former classification by the Organisation for Economic Co-operation and Development. The EU (Eurozone) consists of Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, the Netherlands, Portugal, Slovakia, Spain, and Sweden.

Source(s)

Federal Reserve, Economic Research and Data, Foreign Exchange Rates, https://www.federalreserve.gov/releases/h10/current/, accessed 15 August 2017; IHS Global Insight, World Industry Service database (2016). See Appendix Table 6-8.

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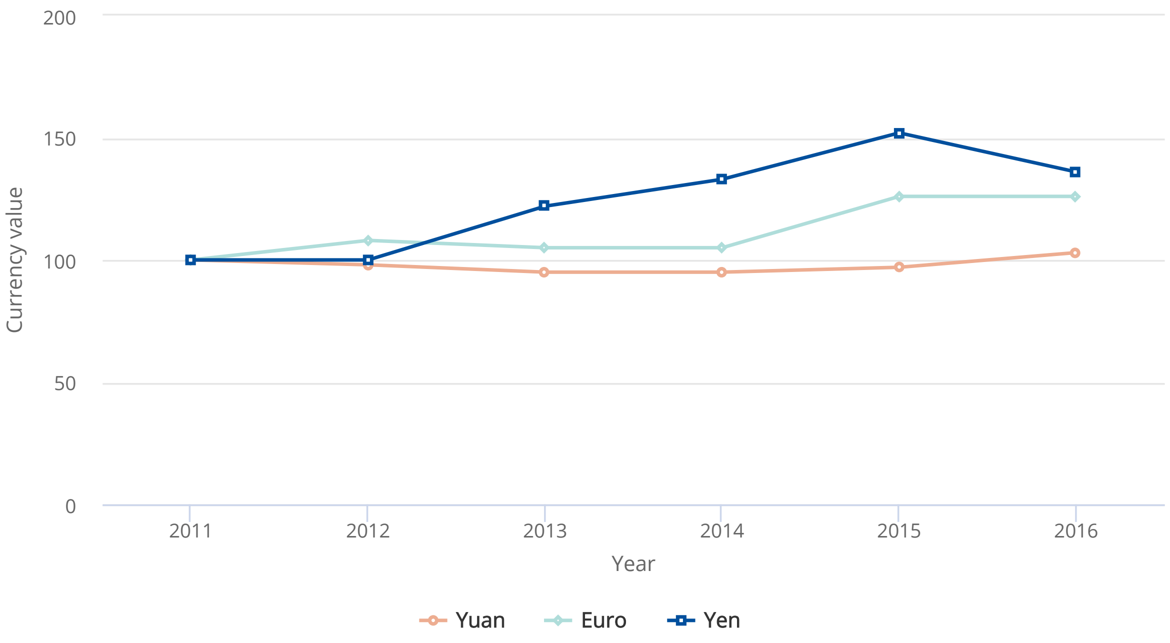
International comparisons of industry, trade, investment, and other global economic activities often use current dollars at market exchange rates. Most global economic activities are dollar denominated, which facilitates comparison. In addition, many economists believe that market exchange rates reflect, at least to some degree, differences in economic performance among various countries (Balke, Ma, and Wohar 2013:2).

However, fluctuations in exchange rates may also reflect factors other than economic performance. Governments influence the level of their exchange rate indirectly through macroeconomic policies and directly through buying and selling currencies. In addition, factors such as political instability or the short-term effects of global financial events on a country's economy can cause currency fluctuations that are unrelated to enduring differences in national economic performance. Comparing economic data from different countries in current dollar terms provides a broadly indicative reflection of a country's relative economic performance.

Between 2011 and 2016, the exchange rates of the world's four largest economies—China, the EU member countries that use the euro (the eurozone), Japan, and the United States—exhibited some fluctuations (Figure 6-B) with substantial depreciation of the euro (26%) and Japanese yen (36%) against the dollar. The yuan's exchange rate, which is controlled by China's government, showed little change against the dollar.

FIGURE 6-B

U.S. dollar exchange rate with selected currencies: 2011–16



Note(s)

Currency value is expressed as an index of 100 in 2011.

Source(s)

Federal Reserve, Economic and Research and Data, Foreign Exchange Rates, https://www.federalreserve.gov/releases/h10/current/, accessed 24 July 2017.

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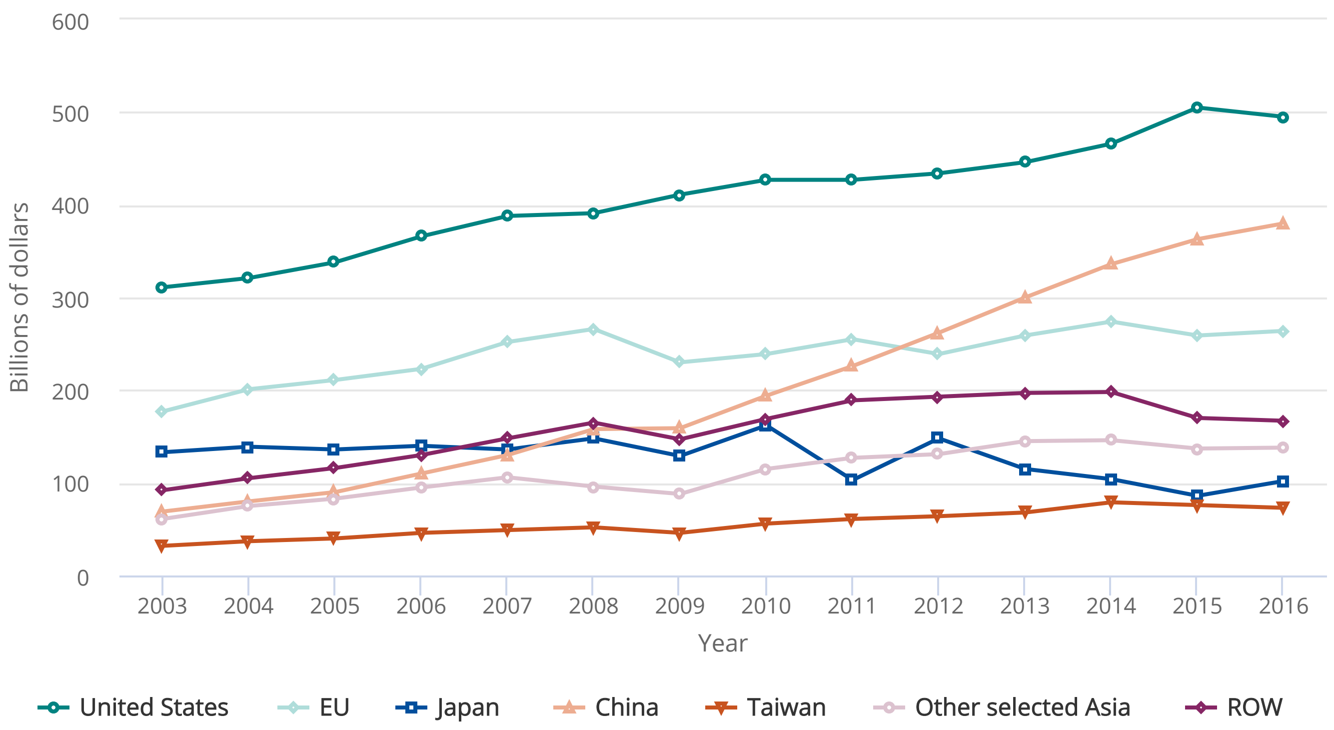
Global Trends in High-Technology Manufacturing Industries

Global value added of high-technology manufacturing was $1.6 trillion in 2016, making up 14% of total manufacturing output (Figure 6-1 and Figure 6-11; Appendix Table 6-8 and Appendix Table 6-13). The three ICT manufacturing industries—semiconductors, computers, and communications—are highly globalized and involve complex value chains in the production process. These ICT industries made up a collective $0.6 trillion in global value added (Appendix Table 6-14, Appendix Table 6-15, and Appendix Table 6-16). Many ICT products such as consumer electronics have short development cycles that require production of large quantities in a short period. The rapid and massive scale-up of production requires a location that can quickly ramp up large-scale production with skilled labor, including engineers and production workers (Donofrio and Whitefoot 2015: 26).

FIGURE 6-11

Output of HT manufacturing industries for selected regions, countries, or economies: 2003–16



EU = European Union; HT = high technology; ROW = rest of world.

Note(s)

Output is measured on a value added basis. Value added is the amount contributed by a country, firm, or other entity to the value of a good or service and excludes purchases of domestic and imported materials and inputs. HT manufacturing industries include aircraft and spacecraft; communications and semiconductors; computers; pharmaceuticals; and testing, measuring, and control instruments. Data are not available for EU members Cyprus, Estonia, Latvia, Lithuania, Luxembourg, Malta, and Slovenia. China includes Hong Kong. Other selected Asia includes India, Indonesia, Malaysia, Philippines, Singapore, South Korea, Taiwan, and Vietnam.

Source(s)

IHS Global Insight, World Industry Service database (2017). See Appendix Table 6-8.

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The three remaining high-technology industries are pharmaceuticals ($540 billion); testing, measuring, and control instruments ($280 billion); and aircraft and spacecraft ($190 billion) (Appendix Table 6-17, Appendix Table 6-18, and Appendix Table 6-19). In the aerospace industry, Airbus and Boeing have globalized their production networks in response to rapidly growing markets outside their domestic regions and pressure to reduce labor and other costs, and to comply with requirements by some countries to locally produce components and supplies (Treuner et al. 2014:7). The global networks benefit from more immediate access to raw materials and engineering capacities and low labor cost. The pharmaceuticals industry has two main global value chains. For emerging and complex biologic vaccines and stem cell therapies, pharmaceutical companies generally locate closely with academic and medical R&D laboratories because these innovative products require close integration of R&D, testing, and manufacturing. For existing and mature technologies, such as small molecules and generics, companies do not need to locate near research laboratories because close integration of R&D and manufacturing is not necessary (Donofrio and Whitefoot 2015:25–26).

The United States is the largest global producer (31% global share) of high-technology manufacturing industries (Figure 6-11 and Appendix Table 6-8). U.S. high-technology manufacturing industries account for a small share of the U.S. industrial output and industry employment (Figure 6-8). However, they fund a disproportionately large share of U.S. business R&D. China is the second largest global producer, with a global share of 24%. The EU is the third largest producer (16%). Japan and Taiwan are roughly tied as the fourth largest producers (6% and 5%, respectively) (Figure 6-11; Appendix Table 6-8).

High-Technology Manufacturing Industries in the United States

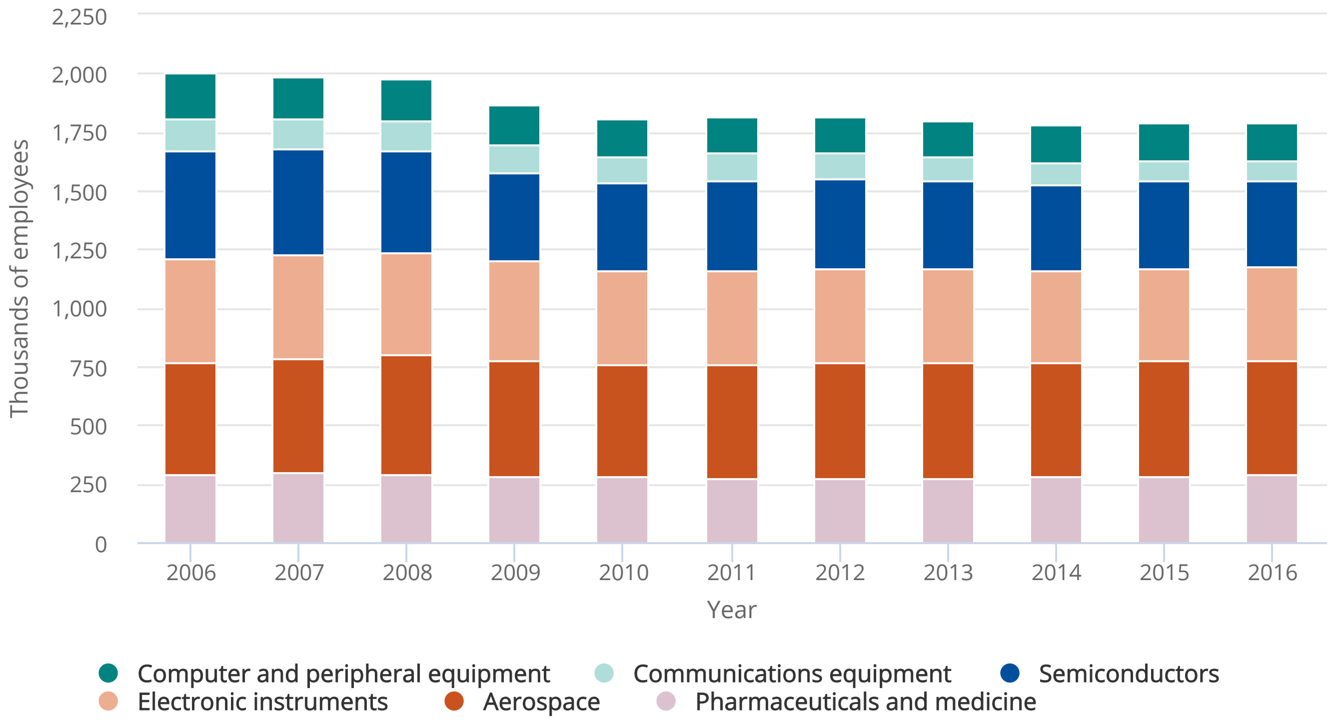
U.S. high-technology manufacturing has grown steadily in the post-global recession period coinciding with its moderate recovery from the global recession (Figure 6-9 and Figure 6-11; Appendix Table 6-8). Between 2011 and 2016, U.S. high-technology manufacturing output grew far faster (16%) compared to the EU and Japan. However, China's output grew far faster (68%) than the United States, resulting in China substantially narrowing its gap with the United States.

Two high-technology manufacturing industries have contributed the most to post-global recession growth: testing, measuring, and control instruments; and pharmaceuticals (Appendix Table 6-17 and Appendix Table 6-18). The United States is the world's largest producer in testing, measuring, and control instruments (44%) and is the second largest global producer in pharmaceuticals closely behind the EU. In the pharmaceuticals industry, production of biologics, vaccines, and stem cell therapies is concentrated in these two economies, where close integration of research, testing, and manufacturing is necessary (Donofrio and Whitefoot 2015:25). The United States is also the dominant global producer in aircraft and spacecraft (53%).

Despite a recovery in output following the global recession, overall U.S. employment in high-technology manufacturing industries has not increased (Figure 6-12). Employment has remained stagnant in the post-global recession period and remains slightly below its level prior to the global recession. The lack of employment growth reflects the relocation of production to China and other countries with lower costs, greater manufacturing scale, or both, as well as the use of robotics and machines in U.S. high-technology manufacturing industries, which have eliminated some jobs, particularly those in routine tasks. Some researchers and policymakers have concluded that the location of high-technology manufacturing and R&D activities may lead to the migration of higher-value activities abroad (Fuchs and Kirchain 2010:2,344).

FIGURE 6-12

U.S. employment in HT manufacturing industries: 2006–16



HT = high technology.

Note(s)

HT manufacturing industries are based on a former classification by the Organisation for Economic Co-operation and Development. HT manufacturing industries include aircraft and spacecraft; communications and semiconductors; computers; pharmaceuticals; and testing, measuring, and control instruments.

Source(s)

Bureau of Labor Statistics, Current Employment Statistics (2016), https://www.bls.gov/ces/, accessed 15 August 2017.

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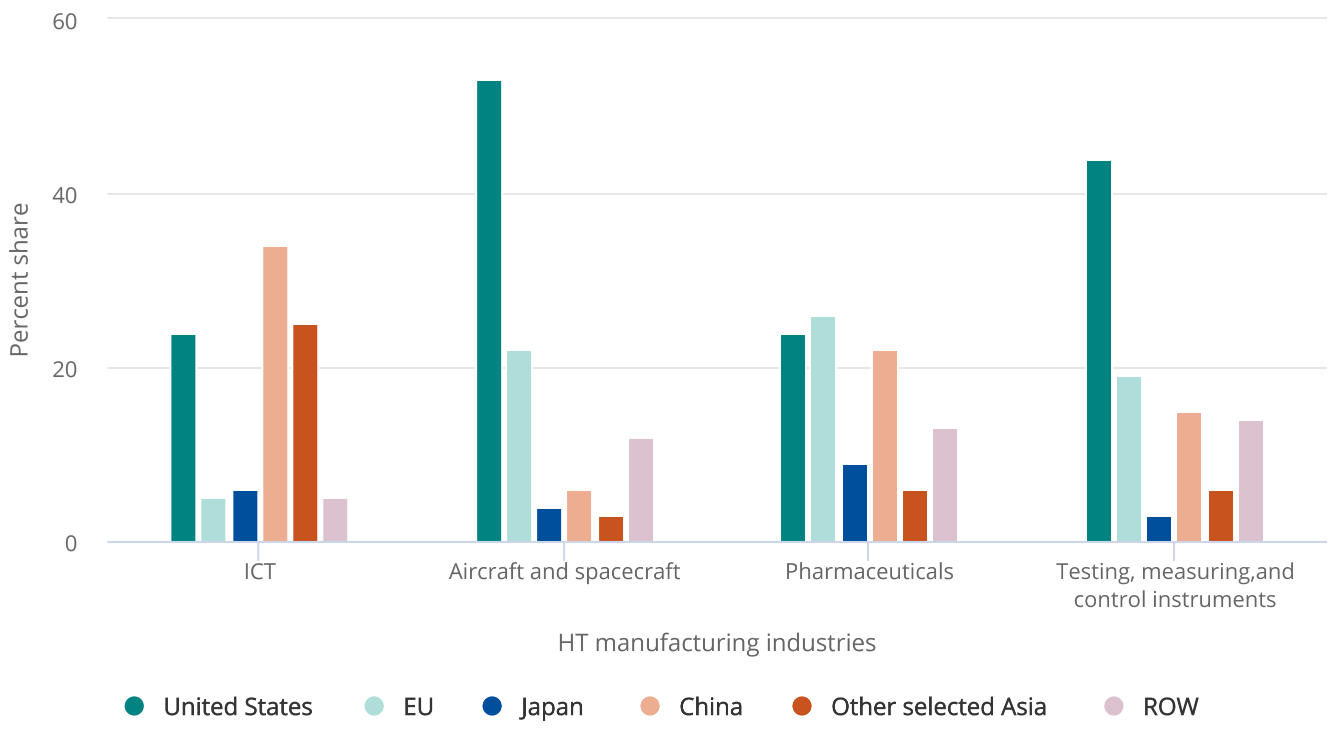
U.S. companies invest a considerable amount of their R&D in three high-technology manufacturing industries—testing, measuring, and control instruments; pharmaceuticals; and aircraft and spacecraft.[8] In addition, manufacturing of aircraft and spacecraft involves a supply chain of other high-technology inputs—navigational instruments, computing machinery, and communications equipment—many of which continue to be provided by U.S. suppliers. Boeing sources about 70% of the parts from U.S.-based companies and 30% from companies outside the United States to produce its advanced 787 airliner and other similar models (Kavilanz 2013). In pharmaceuticals and medical devices (medical devices is part of testing, measuring, and control instruments), production, testing, and treatment are often located close to U.S. academic and medical-center laboratories so that companies can conduct close and continuous research collaboration (Donofrio and Whitefoot 2015:25).

Over the last decade, the U.S. global share of high-technology manufacturing output has remained similar despite a gradual increase in the level of output (Figure 6-11; Appendix Table 6-8). Overall, U.S. high-technology manufacturing output grew by more than 30% over the last decade. Three industries have led growth—testing, measuring, and control instruments; pharmaceuticals; and aerospace (Appendix Table 6-17, Appendix Table 6-18, and Appendix Table 6-19). In contrast, output of the U.S. communication and computer industries has declined coinciding with the rapid rise of China in these industries (Appendix Table 6-15 and Appendix Table 6-16). However, the United States retains a stronger position in the communication and computer industries than the EU or Japan (Figure 6-13), which have had much deeper declines over the last decade.

FIGURE 6-13

HT manufacturing industries of selected regions, countries, or economies: 2016



EU = European Union; HT = high technology; ICT = information and communications technology; ROW = rest of world.

Note(s)

HT manufacturing industries are based on a former classification by the Organisation for Economic Co-operation and Development and include aircraft and spacecraft; communications and semiconductors; computers; pharmaceuticals; and testing, measuring, and control instruments. ICT manufacturing industries consist of computers, communications, and semiconductors. Output is measured on a value added basis. Value added is the amount contributed by a country, firm, or other entity to the value of a good or service and excludes purchases of domestic and imported materials and inputs. Data are not available for EU members Cyprus, Estonia, Latvia, Lithuania, Luxembourg, Malta, and Slovenia. China includes Hong Kong. Other selected Asia includes India, Malaysia, Philippines, Singapore, South Korea, Taiwan, Thailand, and Vietnam.

Source(s)

IHS Global Insight, World Industry Service database (2017). See Appendix Table 6-20 and Appendix Table 6-26 through Appendix Table 6-32.

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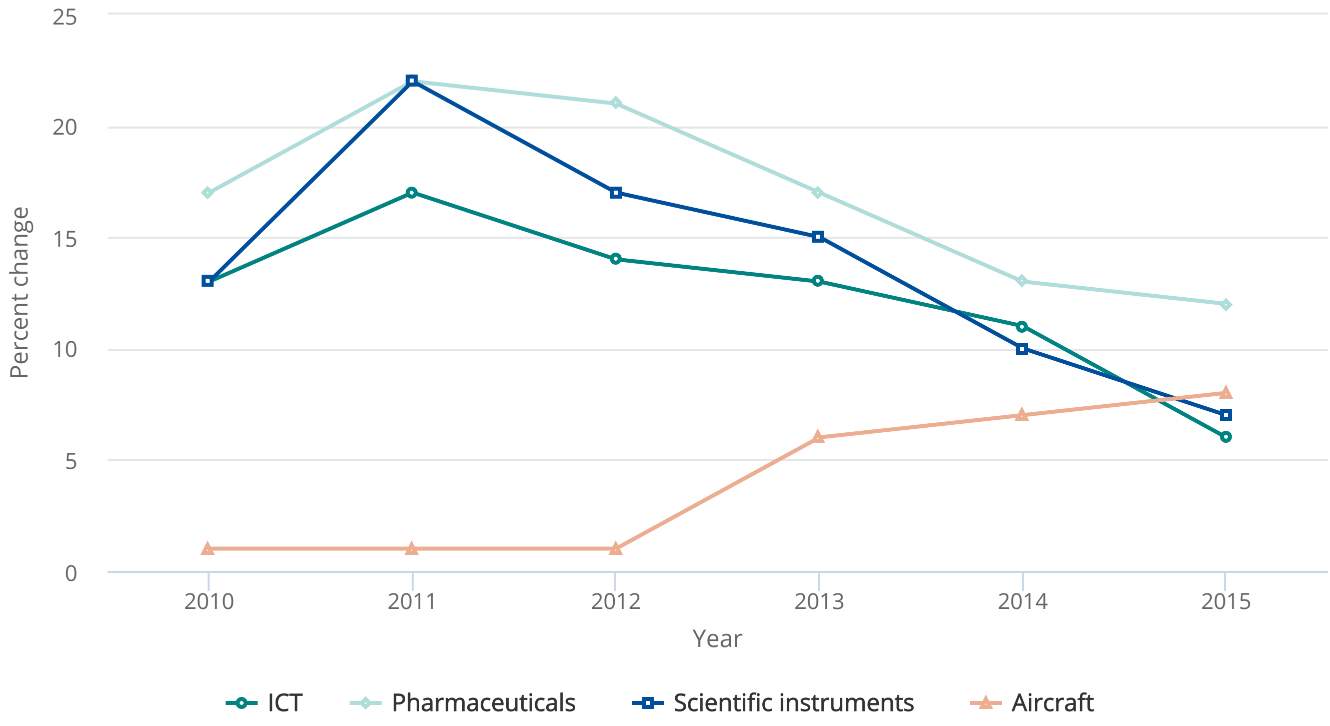
High-Technology Manufacturing Industries in China

China's high-technology manufacturing industries have grown substantially in the post-global recession period, with value-added output growing by 70% between 2011 and 2016, far faster than the United States, EU, or Japan (Figure 6-11; Appendix Table 6-8). However, the growth rate of high-technology industries on a 3-year moving average basis slowed in 2015–16, coinciding with the moderation of China’s economic growth (Figure 6-9 and Figure 6-14). The deceleration in growth was most pronounced in the export-oriented ICT manufacturing industries. The pharmaceuticals industry had the slightest decline in growth among the high-technology industries, with its growth rate overtaking the ICT manufacturing industries in 2015 (Figure 6-13; Appendix Table 6-14 through Appendix Table 6-17). Some observers and researchers believe that the slowdown of China’s high-technology manufacturing and other export-oriented industries also reflects the economy beginning to shift away from export-led to domestic consumption-led growth (Dizioli, Hunt, and Maliszewski 2016:5; Nie and Palmer 2016:26). China’s government adopted the goal of moving the economy from growth based primarily on exports and investment to domestic consumption playing a larger role in supporting its economy in its 12th Five Year Plan for 2011–2016 (Prasad 2015: 4). There is some indication that this policy may be starting to have an impact on the economy. For example, data from the World Bank shows that the private consumption share of GDP increased slightly from 49% to 51% and the share of exports of goods and service fell from 26% to 22% between 2010 and 2015.[9]

FIGURE 6-14

Annual change in value-added output of selected manufacturing industries in China: 2010–15



ICT = information communications technology.

Note(s)

Output is measured on a value added basis. Value added is the amount contributed by a country, firm, or other entity to the value of a good or service and excludes purchases of domestic and imported materials and inputs. Change in value added output is based on a 3-year moving average. For example, output in 2015 is the average for 2014–16.

Source(s)

IHS Global Insight, World Industry Service database (2017). See Appendix Table 6-20 and Appendix Table 6-26 through Appendix Table 6-32.

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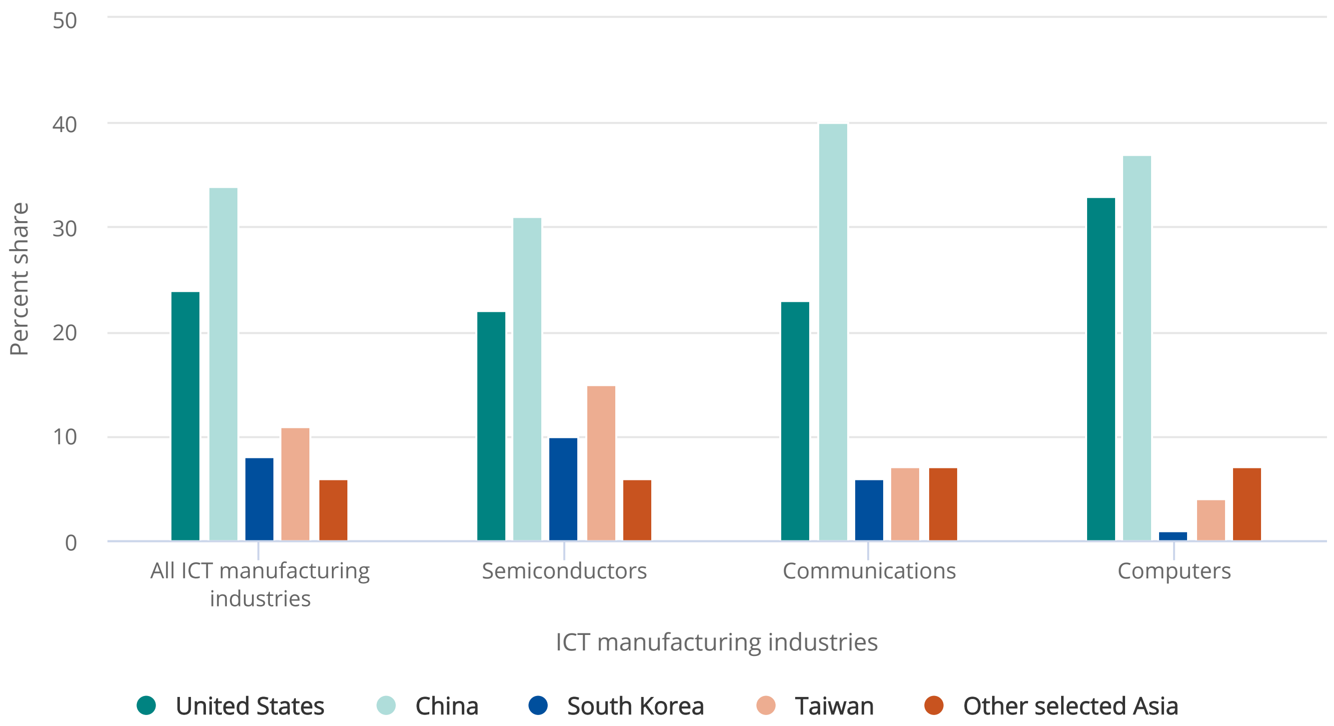
Over the last decade, China's global share in high-technology manufacturing more than doubled (10%–24%), and it surpassed Japan in 2008 and the EU in 2012 to become the world's second largest producer (Figure 6-11; Appendix Table 6-8). China had the most rapid growth in its ICT manufacturing industries resulting in its global share more than doubling from 14% to 34% (Figure 6-15; Appendix Table 6-14, Appendix Table 6-15, and Appendix Table 6-16). China overtook the United States in 2013 to become the world's largest global producer in ICT manufacturing industries.

FIGURE 6-15

Global share of selected regions, countries, or economies in ICT manufacturing industries: 2016



ICT = information and communications technology.

Note(s)

ICT manufacturing industries consist of computers, communications, and semiconductors. Output is measured on a value added basis. Value added is the amount contributed by a country, firm, or other entity to the value of a good or service and excludes purchases of domestic and imported materials and inputs. China includes Hong Kong. Other selected Asia includes Malaysia, Philippines, Singapore, Thailand, Taiwan, and Vietnam.

Source(s)

IHS Global Insight, World Industry Service database (2017). See Appendix Table 6-20 and Appendix Table 6-26 through Appendix Table 6-32.

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China functions as the final assembly location for ICT goods assembled in "Factory Asia"—the electronics goods production network centered in East Asia (WTO and IDE-JETRO 2011:14–15). China has global manufacturing scale, a network of suppliers, a large labor force of skilled and production workers, and the ability to quickly ramp up production that is required for many ICT products that have short development cycles (Donofrio and Whitefoot 2015:26). South Korea and Taiwan are major global producers in semiconductors and communications that supply advanced components and inputs to China. Asian countries that supply components and inputs to China, perform final assembly of ICT goods, or both include Indonesia, Malaysia, Philippines, Thailand, and Vietnam.

China has also become a major global producer of pharmaceuticals with its global share tripling over the last decade to reach 22% in 2016 to become the world's third largest producer (Figure 6-13; Appendix Table 6-17). China's rapid growth has originated from production of generic drugs by China-based firms and the establishment of production facilities controlled by U.S. and EU multinationals, often in partnership with Chinese companies. The rapidly expanding middle class, reform of China's health care system, and increasing demand for health care has fueled the rapid expansion of China's pharmaceuticals industry.[10] China's pharmaceuticals industry largely produces mature and existing technologies, such as generics, that do not require close integration of production with R&D. However, China's industry is expected to move into emerging and complex technologies as companies invest in R&D facilities and research collaborations increase with academia (Donofrio and Whitefoot 2015:26). Output of China's testing, measuring, and control instruments industry has grown rapidly, although from a low base (Appendix Table 6-18).

China has been moving up the value chain in manufacture of high-technology goods, albeit progress has been uneven.[11] For example, China has made impressive progress in its supercomputing ability over the last few years, an area that it had little presence in a decade ago (see sidebar China's Progress in Supercomputers).[12] The first large Chinese-made jetliner, the C919, successfully completed its maiden test flight in 2017, a key step in China's plan to move up the value chain and become a global competitor in advanced technologies. Although more than 200 Chinese companies and 36 universities have been involved in the research and development of the C919, the plane relies on foreign-made technology for critical systems, including its engines.[13] Although Chinese semiconductor companies have gained global market share, China remains very reliant on semiconductors supplied by foreign firms for most of its production of smartphones and other electronic products (PwC 2014). Chinese-owned high-technology companies have not met many of the ambitious targets and goals of the Chinese government's indigenous innovation program. China's rapidly growing domestic market is prompting some foreign high-technology firms to establish R&D laboratories to develop products for China's rapidly growing consumer market. However, many multinational companies (MNCs) continue to conduct some of their higher value-added activities in developed countries because of the greater availability of skilled workers, stronger intellectual property protection, or both. In addition, researchers surveyed by the Industrial Research Association perceived the quality of China's R&D to be far lower than the United States.[14]

Anecdotal reports suggest that final assembly has migrated from China to other developed Asian economies or has returned to developed countries in response to increases in transportation costs and China's manufacturing wages.[15] However, China remains an attractive location for foreign MNCs because of its well-developed and global manufacturing scale that has an extensive network of domestic suppliers. In addition, the cost of wages in capital-intensive manufacturing industries, such as ICT, is not a major factor in choosing the location of production facilities because wages are a very small share of production costs. Factors including the cost of land and energy and manufacturing scale typically are more important factors in determining the location of production facilities.[16]

SIDEBAR

China's Progress in Supercomputers

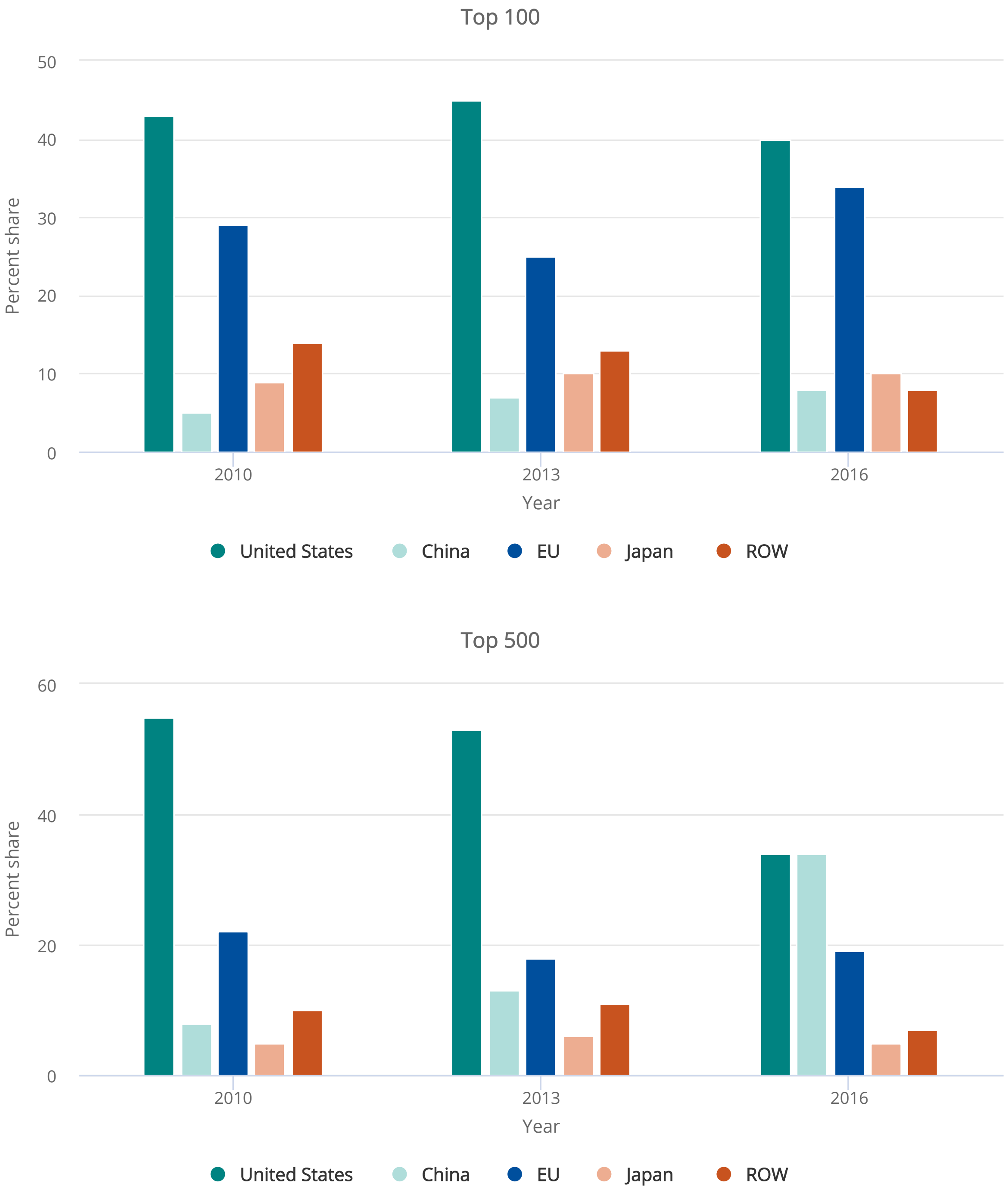
The TOP500, an organization composed of computer scientists and industry specialists, has been tracking the world's most powerful and fastest-performing supercomputers since 1993. The TOP500 provides a semiannual update of the world's top 500 supercomputers, including information on the country of origin, performance, type of application, and technology.

According to the TOP500's November 2016 report, two supercomputers in China were ranked first and second in the world, giving China two slots in the top 10 list. The world's first-ranked computer is the 93-petaflop Sunway TaihuLight supercomputer at the National Supercomputing Center in Wuxi.* The second-ranked computer is the 34-petaflop Tianhe-2 (MilkyWay-2) in the National Supercomputer Center in Guangzhou. The United States continued to have the largest share of supercomputers in the TOP10, with five in the 2016 list. In addition, China reached parity with the United States in the total number of supercomputers (171) ranked in the top 500 list (Figure 6-C). China has made rapid progress over the last several years, with its share rising from 8% in 2010 to 34% in 2016. The U.S. share has fallen sharply from 55% in 2010 to 34% in 2016.

Although its achievements are impressive, China's supercomputing ability remains limited. Much of China's supercomputing capability is concentrated in its two supercomputers that are ranked first and second in the world (Feldman 2017). Together, they represent more than half of the aggregate performance of the country's supercomputers in the TOP500 list. The majority of China's supercomputers reside in the bottom half of the TOP500 list. Although China and the United States have the same number of supercomputers in the TOP500 list, China's median rank is 316, compared to 227 for the United States. China has made far more limited progress in the TOP100-ranked supercomputers. Between 2010 and 2016, China's share rose from 5% to 8% (Figure 6-C). The United States and the EU remain dominant in the TOP100, with shares of 40% and 34%, respectively, in 2016.

FIGURE 6-C

Top-ranked supercomputers, by location of region, country, or economy: 2010–16



EU = European Union; ROW = rest of world.

Source(s)

TOP500 November 2016, 2013, and 2010 reports, https://www.top500.org/lists/, accessed 15 February 2017.

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In addition, the majority of the Chinese supercomputers in the TOP500 list are probably not being used for applications that require the processing ability of supercomputers, including quantum mechanics, weather forecasting, climate research, oil and gas exploration, and molecular modeling and physical simulations. Of the 171 Chinese supercomputers in the TOP500 list, 114 are installed at Internet data center companies, cloud service providers, telecommunications firms, and electric companies (Feldman 2017). These supercomputers have less advanced technology and capability than leading-edge supercomputers and are likely being used for routine activities such as running Web-based or back-office applications. In contrast, most U.S.-based supercomputers are installed at federal national laboratories, universities, and research institutes (Feldman 2017).

* One petaflop is equivalent to one thousand million million (10^{15}) floating-point operations per second.

High-Technology Manufacturing Industries in the EU

Growth of high-technology manufacturing industries in the EU has trailed that in the United States in the post-global recession period (Figure 6-11; Appendix Table 6-8), similar to trends seen in the commercial knowledge-intensive services sector. The EU's output remained relatively flat between 2011 and 2016, coinciding with its lackluster economic growth (Figure 6-9). The EU's global share slipped from 18% to 16% during this period. Although aircraft and spacecraft and pharmaceuticals each grew 14%, output in the ICT manufacturing industries contracted 27% (Appendix Table 6-14 through Appendix Table 6-17, and Appendix Table 6-19). The EU is the largest global producer in pharmaceuticals (26% global share in 2016) (Figure 6-13). The EU is the second largest global producer in aircraft and spacecraft (22% global share) and testing, measuring, and control equipment (19% global share) (Appendix Table 6-18).

High-Technology Manufacturing Industries in Japan and Taiwan

Output of Japan's high-technology manufacturing industries was stagnant between 2011 and 2016, coinciding with its weak and halting recovery from the global recession (Figure 6-9 and Figure 6-11; Appendix Table 6-8). Over the last decade, value-added output contracted by 27%, resulting in Japan's global share dropping from 13% to 6%. Output of ICT industries alone fell by 54%. Japan's deep decline coincides with the decade-long stagnation of its economy, the loss of competitiveness of Japanese electronics firms, and the transfer of production to China and other countries (Appendix Table 6-14, Appendix Table 6-15, and Appendix Table 6-16).

Taiwan's output rose by 19% between 2011 and 2016, almost entirely due to gains in its ICT industries, which dominate its high-technology manufacturing industries. Taiwan is the third largest global producer of ICT manufacturing industries (11%) after China and the United States (Figure 6-15; Appendix Table 6-14, Appendix Table 6-15, and Appendix Table 6-16).

High-Technology Manufacturing Industries in Other Countries

Other major Asian producers—Malaysia, Singapore, and South Korea—showed little change in their global shares between 2011 and 2016 (Appendix Table 6-8). Over the last decade, companies based in these economies have moved up the value chain to become producers of semiconductors and other sophisticated components that are supplied to China and other countries. Output in Vietnam more than doubled between 2011 and 2016 (Appendix Table 6-8), largely due to growth in ICT manufacturing industries. Vietnam has become a low-cost location for assembly of cell phones and other ICT products, with some firms shifting production out of China, where labor costs are higher.[17]

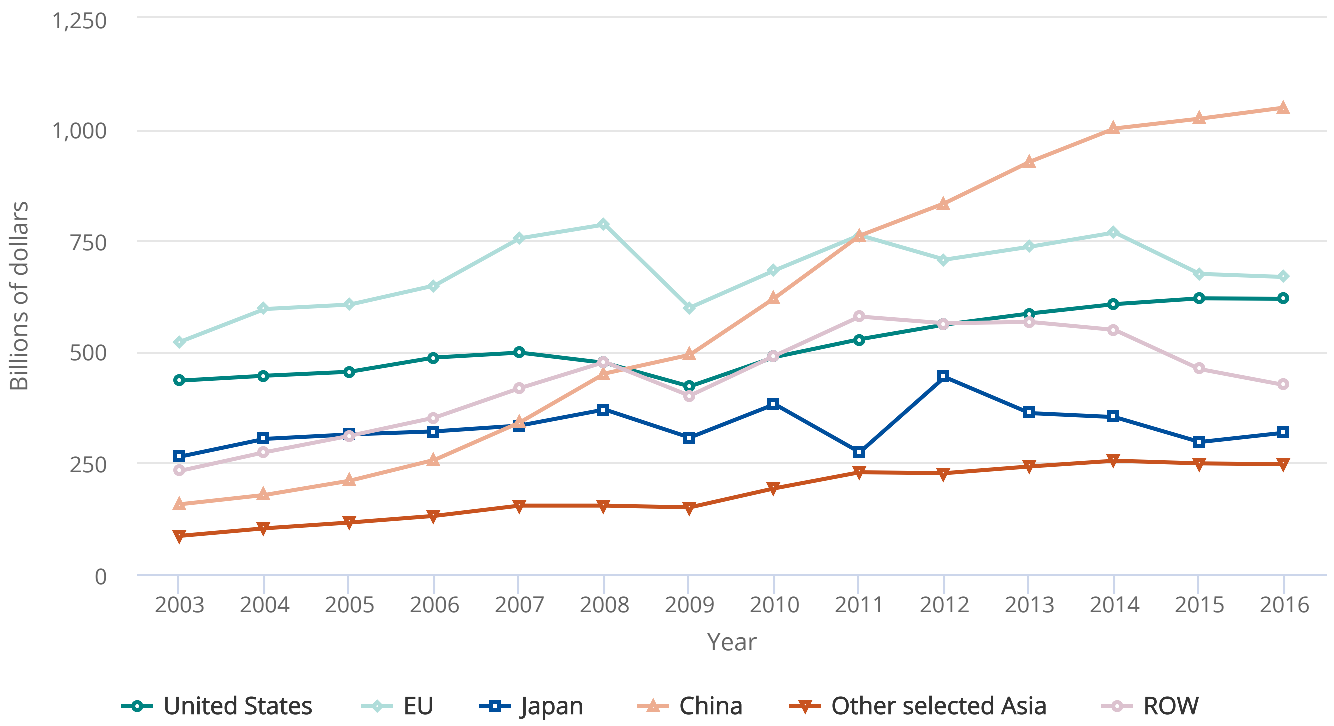
India's high-technology manufacturing output fell 14% during this period. India is a major producer in the pharmaceuticals industry (2% global share), with Indian firms manufacturing generic drugs and performing clinical trials for multinational pharmaceutical companies based in the United States and the EU (Appendix Table 6-8 and Appendix Table 6-17).[18]

Global Trends in Medium-High-Technology Industries

Global value added of medium-high-technology manufacturing was $3.3 trillion in 2016, about twice as large as high tech manufacturing, making up 29% of the manufacturing sector (📊 Figure 6-1 and 📊 Figure 6-16; Appendix Table 6-7 and Appendix Table 6-13). The three largest industries are chemicals excluding pharmaceuticals, machinery and equipment, and motor vehicles and parts ($0.8–$0.9 trillion in output) (Appendix Table 6-20, Appendix Table 6-21, and Appendix Table 6-22). The fourth largest industry is electrical machinery and appliances ($0.5 trillion) (Appendix Table 6-23). Railroad and other transportation equipment is a far smaller industry ($0.1 trillion) (Appendix Table 6-24).

FIGURE 6-16

Output of MHT manufacturing industries for selected regions, countries, or economies: 2003–16



EU = European Union; MHT = medium-high technology; ROW = rest of world.

Note(s)

Output is measured on a value added basis. Value added is the amount contributed by a country, firm, or other entity to the value of a good or service and excludes purchases of domestic and imported materials and inputs. MHT manufacturing industries are based on a former classification by the Organisation for Economic Co-operation and Development and include motor vehicles and parts, electrical machinery, machinery and equipment, chemicals excluding pharmaceuticals, and railroad and other transportation equipment. Data are not available for EU members Cyprus, Estonia, Latvia, Lithuania, Luxembourg, Malta, and Slovenia. China includes Hong Kong. Other selected Asia includes India, Indonesia, Malaysia, Philippines, Singapore, South Korea,Taiwan, and Vietnam.

Source(s)

IHS Global Insight, World Industry Service database (2017). See Appendix Table 6-8.

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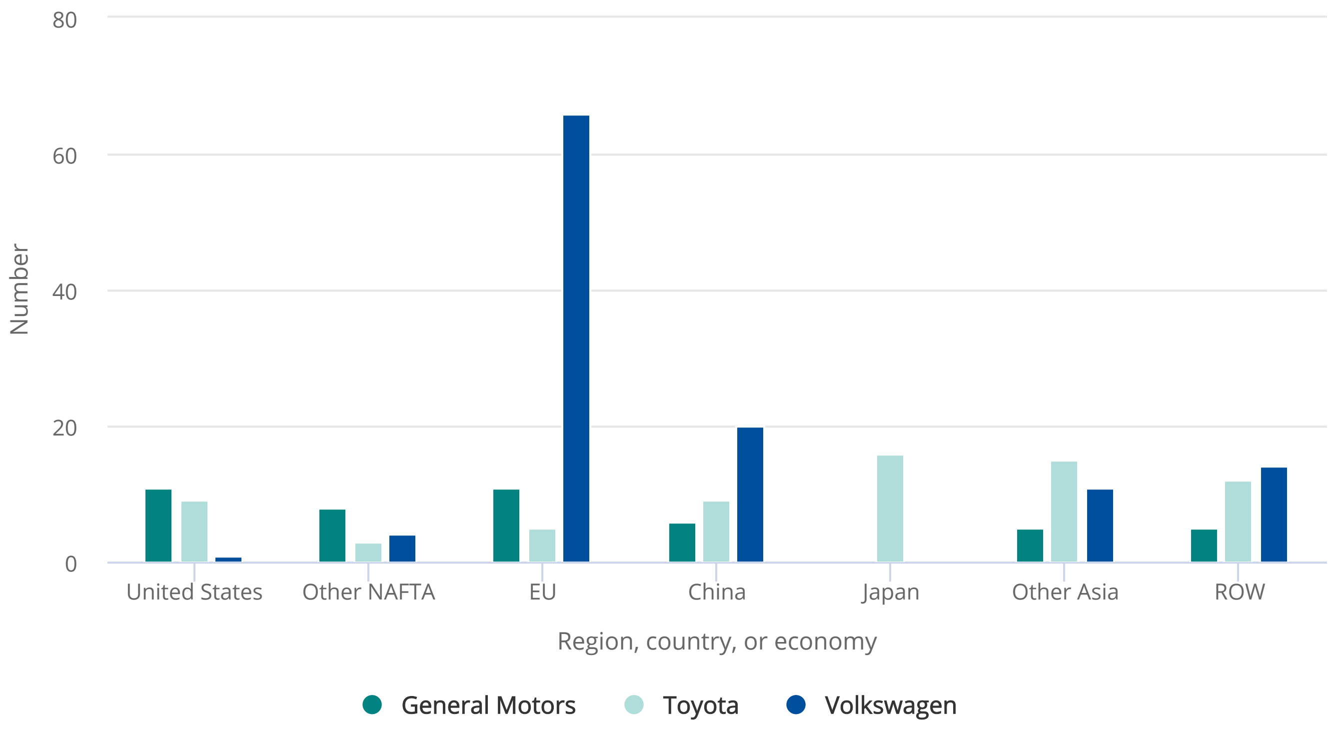
Although these industries have global and often complex value chains, production activities are generally located closer to the final market compared to consumer electronics and other ICT industries with lightweight products (Donofrio and Whitefoot 2015:25). Because many inputs and components are manufactured near or at the final market, the value added may be credited to the company's subsidiary or contractor. For example, in the motor vehicles and parts industry, the manufacturing facilities of three major global automakers—General Motors, Toyota, and Volkswagen—are widely dispersed and clustered in the regions or countries of their final markets (Figure 6-17). Transportation costs are high in many of these industries because the final products and major components in many of these industries are large and heavy, particularly automobiles, large appliances, and heavy equipment. Furthermore, co-location of R&D and design near the customers is advantageous for understanding customer needs and local market demand (Donofrio and Whitefoot 2015:25).

FIGURE 6-17

Manufacturing facilities of General Motors, Toyota, and Volkswagen, by selected region, country, or economy: 2016



EU = European Union; NAFTA = North American Free Trade Agreement; ROW = rest of world.

Note(s)

Other Asia includes India, Malaysia, Philippines, South Korea, Taiwan, Thailand, and Vietnam.

Source(s)

Toyota, http://www.toyota-global.com/company/profile/facilities/, accessed 14 February 2017; General Motors, https://media.gm.com/media/us/en/gm/plants-facilities.html, accessed 14 February 2017; Volkswagen, https://www.volkswagenag.com/en/group/portrait-and-production-plants.html, accessed 14 February 2017.

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China is the largest global producer (32% global share) (Figure 6-16; Appendix Table 6-7) in medium-high-technology manufacturing industries. The EU is second (20%) closely followed by the United States (19%). Japan is the fourth largest producer (10%).

Medium-High-Technology Industries in China

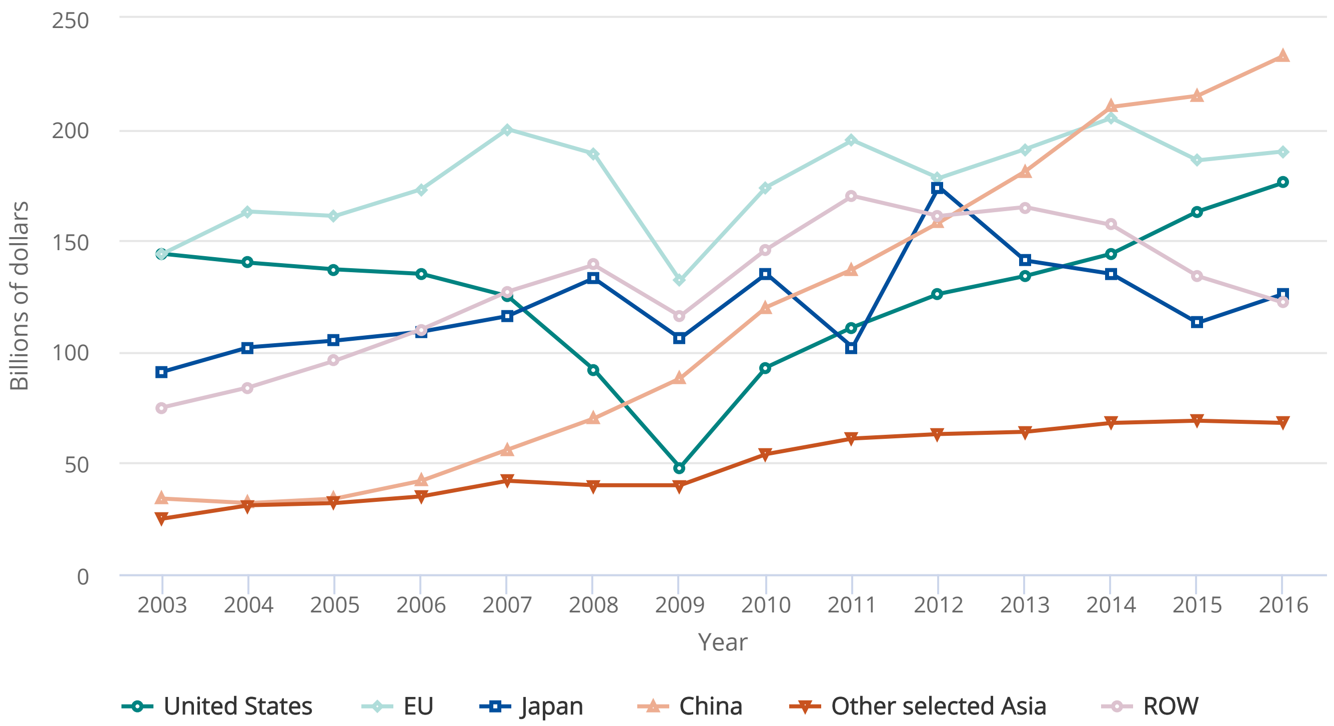
China’s medium-high-technology manufacturing industries grew 38% between 2011 and 2016 (Figure 6-16; Appendix Table 6-7). Growth in output of these industries slowed significantly in 2015–16, similar to the moderation in growth of China’s high-technology manufacturing industries.

China surpassed the United States in 2009 to become the world’s second largest producer in medium-high-technology industries and surpassed the EU in 2012 to become the world’s largest producer. The motor vehicle and parts industry led growth in China, with output rising almost sixfold over the last decade (Figure 6-18; Appendix Table 6-20). China’s automobile industry is composed of joint ventures with multinational companies and indigenous manufacturers. Although most cars and trucks manufactured in China are sold for the rapidly growing domestic market, China’s industry is exporting an increasing number of cars, trucks, and parts (see "China's Trade in Medium-High-Technology Goods" in section Global Trade in Commercial Knowledge- and Technology-Intensive Goods and Services).[19]

China surpassed the United States to become the world’s largest producer of chemicals (excluding pharmaceuticals) in 2013 (28% global share in 2016) (Appendix Table 6-21). China accounts for nearly half of global production in electrical machinery and appliances (44%) and is the largest global producer in machinery and equipment (32%) (Appendix Table 6-22 and Appendix Table 6-23).

FIGURE 6-18

Output of motor vehicles and parts industry for selected regions, countries, or economies: 2003–16



EU = European Union; ROW = rest of world.

Note(s)

Value added is the amount contributed by a country, firm, or other entity to the value of a good or service and excludes purchases of domestic and imported materials and inputs. Medium-high technology manufacturing industries are based on a former classification by the Organisation for Economic Co-operation and Development and include automotive; chemicals (excluding pharmaceuticals); electrical machinery; motor vehicles; railroad, shipbuilding, and other transportation equipment; and machinery, equipment, and appliances. Data are not available for EU members Cyprus, Estonia, Latvia, Lithuania, Luxembourg, Malta, and Slovenia. China includes Hong Kong. Other selected Asia includes India, Indonesia, Malaysia, Philippines, Singapore, South Korea,Taiwan, and Vietnam.

Source(s)

IHS Global Insight, World Industry Service database (2017). See Appendix Table 6-8.

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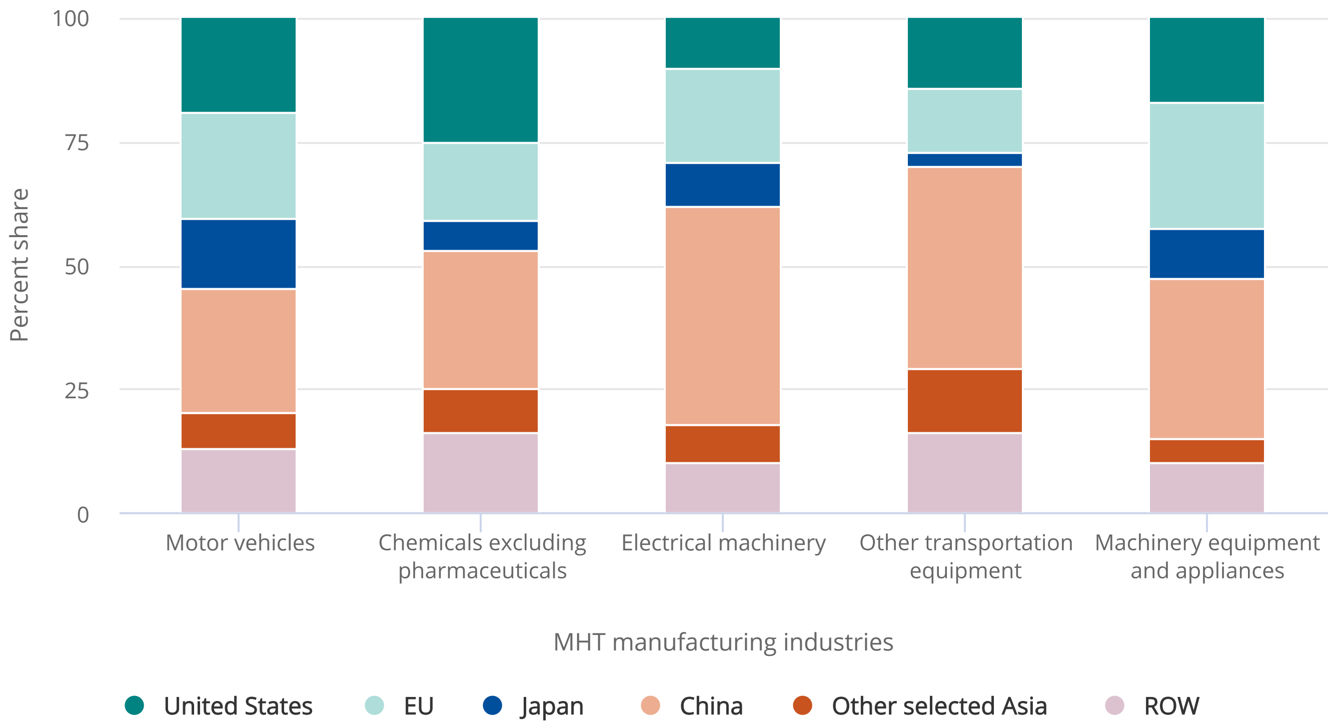
Medium-High-Technology Industries in the United States

U.S. medium-high-technology manufacturing industries grew at the same pace as Japan in the 2011–16 post-global recession period (16%–17%). Output of the EU's industries contracted by 12% during this period. However, China grew far faster (38%) than the United States (Figure 6-16; Appendix Table 6-7). Just like in China, the motor vehicle and parts industry drove overall growth of these industries in the United States, with output rising nearly 60% during this period (Figure 6-18; Appendix Table 6-20). The global share of the U.S. motor vehicle industry climbed from 14% to 19% between 2011 and 2016, returning to its pre-global recession level. The United States has the world's third largest motor vehicle industry, behind the EU (21%) and the largest global producer, China (25%) (Figure 6-19).

FIGURE 6-19

Global share of selected regions, countries, or economies of MHT manufacturing industries: 2016



EU = European Union; MHT = medium-high technology; ROW = rest of world.

Note(s)

MHT manufacturing industries include motor vehicles and parts, electrical machinery, machinery and equipment, chemicals excluding pharmaceuticals, and railroad and other transportation equipment. Output is measured on a value added basis. Value added is the amount contributed by a country, firm, or other entity to the value of a good or service and excludes purchases of domestic and imported materials and inputs. Data are not available for EU members Cyprus, Estonia, Latvia, Lithuania, Luxembourg, Malta, and Slovenia. China includes Hong Kong. Other selected Asia includes India, Indonesia, Malaysia, Philippines, Singapore, South Korea, Taiwan, and Vietnam.

Source(s)

IHS Global Insight, World Industry Service database (2017). See Appendix Table 6-20 and Appendix Table 6-26 through Appendix Table 6-32.

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The rapid recovery of the U.S. automobile industry following the global recession has been driven in part by the federal government's bailout and financial restructuring of General Motors and Chrysler in 2009, which restored those firms to profitability and helped preserve the extensive domestic network of suppliers and parts to these and other automotive firms (Klier and Rubenstein 2013:146–55). Sales of motor vehicles and parts soared following the recession due to pent-up demand from the collapse of sales during the recession and greater availability of credit. Many automobiles sold in the United States by U.S. and foreign-based companies are manufactured in plants and use suppliers and parts located in the United States or nearby in Canada or Mexico.[20] In addition, many of these companies have R&D facilities in the United States to understand customer needs and quickly modify or innovate in design, capabilities, or the manufacturing process.[21]

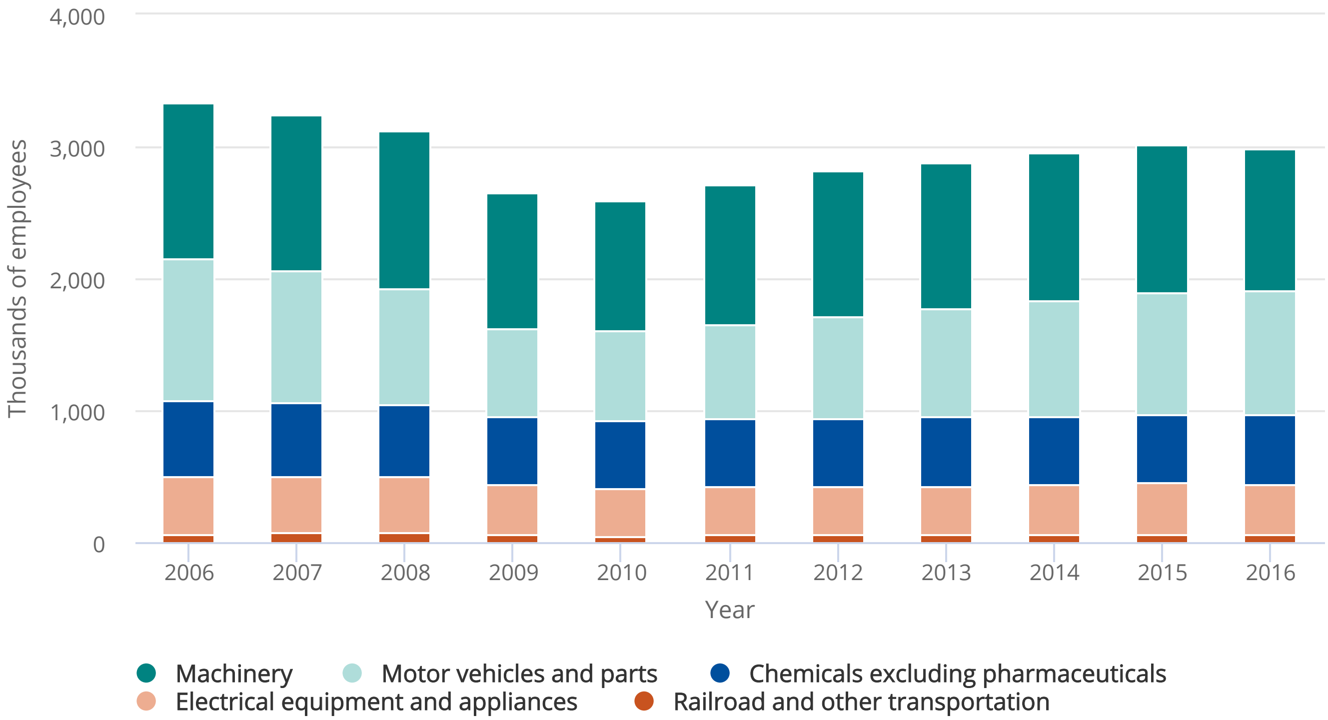
In other industries, output in electrical machinery and appliances increased by 17% between 2011 and 2016 (Appendix Table 6-23). The U.S. global share in this industry remained flat during this period (11% in 2016). Growth was sluggish in chemicals excluding pharmaceuticals (5%) and in machinery and equipment (7%) (Appendix Table 6-21 and Appendix Table 6-22). The United States is the second largest global producer of chemicals excluding pharmaceuticals (25%) closely behind China. The United States is the third largest global producer of machinery and equipment (17% global share).

Over the last decade, the U.S. global share of medium-high-technology manufacturing has slipped from 22% to 19%, largely due to much faster growth in China (Figure 6-16; Appendix Table 6-7). Despite the slight decline in the U.S. global share, U.S. medium-high-technology manufacturing output grew by 27% over the last decade. Chemicals excluding pharmaceuticals and motor vehicles and parts drove growth of these industries, with output rising by 39% and 31%, respectively (Appendix Table 6-20, Appendix Table 6-21).

U.S. employment in medium-high-technology manufacturing has grown substantially in the post-global recession period, adding 280,000 jobs to reach 3.0 million in 2016 (Figure 6-20). The motor vehicle industry drove the gain in employment with the addition of 220,000 jobs. Despite this robust growth, employment in medium-high-technology manufacturing industries remains slightly below its level prior to the global recession.

FIGURE 6-20

U.S. employment in MHT manufacturing industries: 2006–16



MHT = medium-high technology.

Note(s)

MHT manufacturing industries are based on a former classification by the Organisation for Economic Co-operation and Development and include automotive; chemicals (excluding pharmaceuticals); electrical machinery; motor vehicles; railroad and other transportation equipment; and machinery, equipment, and appliances.

Source(s)

Bureau of Labor Statistics, Current Employment Statistics (2016), https://www.bls.gov/ces/, accessed 15 August 2017.

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Medium-High-Technology Industries in the EU

The EU's medium-high technology manufacturing industries grew slower than those of the United States. The EU’s output declined by 12% between 2011 and 2016, coinciding with its lackluster economic recovery from the global recession (Figure 6-9). The EU’s global share declined from 24% to 20% during this period.

The extent of decline in EU output varied across individual industries. Output in chemicals excluding pharmaceuticals and electrical machinery and appliances fell by 19% between 2011 and 2016 (Appendix Table 6-21 and Appendix Table 6-23). Output of motor vehicles and parts remained flat (Figure 6-18; Appendix Table 6-20). The German auto industry is the dominant producer in the EU, and companies including BMW, Mercedes, and Volkswagen have been successful in the EU and the global market. In addition, Germany had comparatively stronger growth than other EU countries in the post-global recession period.

Over the last decade, the EU's global share in medium-high-technology manufacturing has fallen substantially (from 30% to 20%) with declines in each of the four industries.

Medium-High-Technology Industries in Japan

Japan's medium-high-technology manufacturing industries grew by 16% between 2011 and 2016, far faster than its high-technology manufacturing industries (Figure 6-11 and Figure 6-16; Appendix Table 6-7 and Appendix Table 6-8). Despite the rise in output, Japan's global share in medium-high technology manufacturing remained flat (10%) during this period.

The motor vehicles and parts industry grew the fastest (23%) followed by a 17% increase each in electrical equipment and appliances and machinery and equipment (Figure 6-18; Appendix Table 6-20, Appendix Table 6-22, and Appendix Table 6-23). Japanese automakers, including Toyota and Honda, are leading global automakers and are very successful in many developed and developing countries. Over the last decade, Japan's global share in medium-high-technology manufacturing has fallen from 15% to 10%, coinciding with the long-term stagnation of Japan's economy and the migration of manufacturing and routine activities to China and other countries. For example, Toyota has more than three-quarters of its manufacturing plants located outside of Japan (Figure 6-17).

Medium-High-Technology Industries in Other Countries

In other developing countries, Brazil, India, Indonesia, and Mexico have global shares of 1%–2% (Appendix Table 6-7). Output in Brazil has fallen steeply in the last several years across all industries due to Brazil's economic recession. Brazil's global share slid from 4% to 2% between 2011 and 2016. India's output was stagnant during this period. Indonesia's output grew 27%, led by strong gains in chemicals excluding pharmaceuticals, electrical equipment and appliances, and machinery and equipment. Mexico's output rose by 7% between 2011 and 2016, led by motor vehicles and parts (29%). Mexico assembles many cars for sale in the United States and has benefitted from the rapid recovery of the U.S. auto industry.

Industries That Are Not Knowledge or Technology Intensive

S&T are used in many industries besides KTI industries. Service industries not classified as knowledge-intensive services—which include wholesale and retail trade, restaurant and hotel, transportation and storage, and real estate—may incorporate advanced technology in their services or in the delivery of their services. Manufacturing industries not classified as high technology or medium-high technology may use advanced manufacturing techniques, incorporate technologically advanced inputs in manufacturing, or perform or rely on R&D. Industries not classified as either manufacturing or services—agriculture, construction, mining, and utility—also may incorporate recent S&T in their products and processes. For example, agriculture relies on breakthroughs in biotechnology, construction uses knowledge from materials science, mining depends on earth sciences, and utilities rely on advances in energy science.

In the non-knowledge-intensive service industries—wholesale and retail trade, restaurant and hotel, transportation and storage, and real estate—the United States, the EU, China, and Japan were the four largest producers in 2016 (Table 6-2). Over the last decade, in all four industry categories, the global shares of the EU and Japan declined; China's global share grew rapidly and by 2016 it surpassed Japan's share. The U.S. global share remained steady in real estate and transport and storage and declined slightly in retail and wholesale trade and restaurants and hotels.

The non-knowledge-intensive manufacturing industries (non-high-technology and non-medium-high-technology manufacturing industries) are divided into two categories, as formerly classified by the OECD: medium-low technology and low technology. In both of these categories, patterns and trends diverged somewhat from those in high-technology manufacturing and were broadly consistent with medium-high-technology manufacturing (Table 6-2). China's global share of value added grew rapidly between 2006 and 2016 (Table 6-2), and it became the world's largest producer by 2016 in both categories. The global shares of the EU and Japan declined in both categories. The U.S. global share fell slightly in medium-low technology industries and had a deeper decline in low-technology manufacturing industries.

TABLE 6-2

Global value added for selected industries, by selected region, country, or economy: 2006 and 2016

(Percent share)

Region, country, or economy	Real estate		Transport and storage		Retail and wholesale trade		Restaurants and hotels		Medium-low-technology manufacturing industries		Low-technology manufacturing industries	
	2006	2016	2006	2016	2006	2016	2006	2016	2006	2016	2006	2016
Global value added (current $billions)	4,534	6,724	2,140	3,049	5,543	7,966	1,216	1,884	2,114	2,698	2,152	3,180
China	3	11	8	16	5	15	5	13	12	30	13	32
EU	32	24	30	22	27	20	31	24	26	17	28	17
Japan	10	8	10	7	9	6	11	9	11	9	9	6
United States	34	33	22	21	32	29	31	29	22	20	21	16

EU = European Union.

Note(s)

Value added is the amount contributed by a country, firm, or other entity to the value of a good or service and excludes purchases of domestic and imported materials and inputs. China includes Hong Kong. Medium-low-technology manufacturing industries consist of building and repairing of ships and boats; rubber and plastics products; coke, refined petroleum products, and nuclear fuel; other nonmetallic mineral products; and basic metal and fabricated metal products and are formerly classified by the Organisation for Economic Co-operation and Development (OECD). Low-technology manufacturing industries include recycling; wood, pulp, paper, paper products, printing, and publishing; food products, beverages, and tobacco; and textiles, textile products, leather, and footwear and are formerly classified by the OECD. The EU excludes Cyprus, Estonia, Latvia, Lithuania, Luxembourg, Malta, and Slovenia.

Source(s)

IHS Global Insight, World Industry Service database (2016).

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In the nonmanufacturing and non-services industries—agriculture, forestry, and fishing; construction; mining; and utilities—China's global share grew substantially between 2006 and 2016 (Table 6-3). China became the world's largest producer in agriculture, and reached parity with the United States and the EU as the largest global producer in construction. China became the second largest global producer in utilities. The global share of the United States fell in these industries. The EU and Japan had generally steeper declines in these industries.

TABLE 6-3

Global value added for selected industries, by selected region, country, or economy: 2006 and 2016

(Percent)

Region, country, or economy	Agriculture, forestry, and fishing		Construction		Mining		Utilities	
	2006	2016	2006	2016	2006	2016	2006	2016
Global value added (current $billions)	2,157	4,050	2,698	3,900	1,760	1,937	1,506	2,048
China	20	35	6	20	9	13	11	22
EU	15	8	31	19	7	3	28	21
Japan	4	2	9	7	0	0	6	3
United States	9	6	26	20	16	14	29	26

EU = European Union.

Note(s)

Value added is the amount contributed by a country, firm, or other entity to the value of a good or service and excludes purchases of domestic and imported materials and inputs. China includes Hong Kong. The EU excludes Cyprus, Estonia, Latvia, Lithuania, Luxembourg, Malta, and Slovenia.

Source(s)

IHS Global Insight, World Industry Service database (2016).

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Identifying industries that are KTI by their industry classification has many limitations. These limitations include (1) firms are classified in one industry although many have activities in multiple industries and (2) the difficulty of capturing the value added contributed by countries and industries for KTI products and services produced in global value chains. “Platform-based” companies, which include Amazon, Facebook, and Uber, are an example of firms that produce KTI goods and services and use innovative technologies that are likely not categorized in KTI industries. The United States is a global leader in these types of companies. (For a discussion of these companies, see sidebar Platform-Based Companies.)

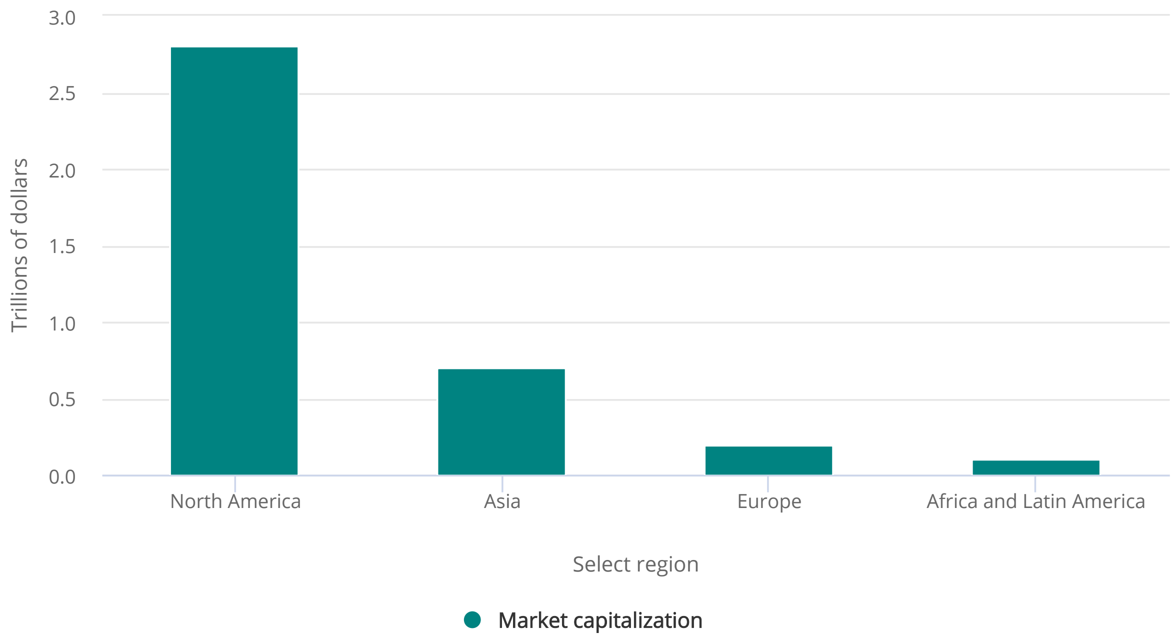
SIDEBAR

Platform-Based Companies

“Platform-based” companies combine a set of marketing and organizational innovations with novel linkages to external resources, including user-created content and data, to create new and innovative business models. These companies combine existing products and services and ICT infrastructure in new ways. They leverage ICT infrastructure and technology to create networks or social media platforms that help create demand for their products and services and provide a vehicle for targeted advertising and collecting extensive data on user’s preferences that can be sold to third parties. Platform-based companies operate in and compete directly and indirectly with traditional companies. For example, Uber is a direct competitor to traditional taxi companies and indirectly competes with automobile manufacturers, as some consumers decide not to own automobiles. Other examples of platform-based companies are Apple, Airbnb, Facebook, Instagram, Google, Amazon, WhatsApp, and Netflix. The United States dominates the new platform-based companies by a wide margin compared to the rest of the world (Figure 6-D) (Sturgeon 2016; Van Alstyne 2016).

FIGURE 6-D

Headquarters of platform companies, by selected region: 2015



Source(s)

Van Alstyne M, Platform Shift: How New Biz Models Are Changing the Shape of Industry (2016), https://ilp.mit.edu/images/conferences/2014/ict/presentations/vanalstyne.ict.2014.pdf.

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[1] Data on the health care sector include social services.

[2] See Bresnahan and Trajtenberg (1995) and DeLong and Summers (2001) for discussions of ICT and general-purpose technologies.

[3] For a discussion of potential economic benefits of the Internet of Things, see Mandel (2013:2–4).

[4] In the education sector, countries compete to attract foreign students to study and train. In the health sector, some countries promote “medical tourism” to attract foreigners to obtain medical care that is often cheaper than that provided in their home country.

[5] See Jensen (2012) for a discussion of U.S. business services firms helping to build infrastructure in developing countries.

[6] This chapter defines the global recession occurring in 2008–2010 and the post-global recession starting in 2011 for consistency of comparing trends across countries. However, the scale and timing of the recession and recovery varies by country.

[7] See China Daily (2016) and KPMG (2009) for a discussion of China's outsourcing of business services to firms in other countries.

[8] The testing, measuring, and navigation instruments industry includes medical and optical equipment.

[9] Source: The World Bank, World Development Indicators database http://data.worldbank.org/data-catalog/world-development-indicators.

[10] China's government has increased subsidies and support for the public health system, expanded insurance coverage of rural residents, encouraged use of private health insurance through tax breaks to policy holders, and changed regulation and financial support to lower costs of drugs to patients and the public health system. See Cao (2014) and Hsu (2015).

[11]See Williamson and Raman (2011) for a discussion of China's acquisition of foreign companies.

[12] China had 18 of its supercomputers listed in the world's top 500 supercomputers in November 2016 (Top 500, https://www.top500.org/statistics/sublist/).

[13]See Watt and Wong (2017).

[14]See Industrial Research Institute (2016).

[15] See *Economist* (2013) for a discussion of multinational firms choosing to have more of their manufacturing take place in developed countries.

[16] For example, the solar photovoltaic manufacturing industry is capital-intensive. See Goodrich et al. (2013:2813–17) for a comparison of the costs of solar PV manufacturing in China and the United States.

[17] See Green (2014) and Tomiyama (2015) for a discussion on the move of electronics manufacturing from China to Vietnam.

[18] See PwC (2014) and Indian Brand Equity Foundation (2017) for information on India's pharmaceutical industry.

[19] China is one of the world's largest exporters of automobile parts. It is now the fourth-largest exporter behind Germany, the United States, and Japan according to AmChamChina (2015).

[20] See Donofrio and Whitefoot (2015:23–27), for a discussion of factors that influence the location of plants and suppliers in the automotive and other industries.

[21] Toyota, among others, has located much of the design and production of its minivans and large pickup trucks in the United States because it is home to many of the customers of these vehicles. See Donofrio and Whitefoot (2015:25).

Global Trends in Trade of Knowledge- and Technology-Intensive Products and Services

The second section of this chapter examines patterns of trade associated with KTI industries in the United States and other economies. (For an explanation of KTI industries, please see section Chapter Overview.) In the modern world economy, production has become more globalized (i.e., value is added to a product or service in more than one nation) and less often vertically integrated (i.e., conducted under the auspices of a single company and its subsidiaries) than in the past. The fragmentation of production into specific activities and across national boundaries has led to the rise of global value chains and has increased trade in intermediate products (OECD, WTO, and World Bank Group 2014). Trade in intermediate goods and services and capital goods accounts for 70% of global trade, an indicator of the globalization and extent of global value chains (OECD 2014:7). Between 1995 and 2009, the cross-border flows of intermediate goods and services, as well as final products associated with manufacturing value chains, significantly increased (Donofrio and Whitefoot 2015:21). Global value chains have allowed developing countries to industrialize faster and gain income and jobs from providing components, supplies, or specific services, rather than creating an entire industry (OECD and WTO 2013:89).

The globalization of production and rise of global value chains have affected all industries, but their impact has been pronounced in many commercial KTI industries, particularly the ICT industries, and medium-high-technology industries, including motor vehicles and parts and electrical machinery and appliances. The broader context is the rapid expansion of these industrial and service capabilities in many developing countries, both for export and internal consumption, accompanied by an increasing supply of skilled, internationally mobile workers. (See Chapter 2 and Chapter 3 for discussions on internationally mobile students and workers.)

This section focuses on cross-border trade of international knowledge-intensive services and high-technology and medium-high-technology products. Trade data are a useful though imperfect indicator of globalization (for a discussion, see sidebar Measurement and Limitations of Trade Data and sidebar Measurement of Trade in Value-Added Terms).

This discussion of trade trends in knowledge-intensive services and high-technology manufactured products focuses on (1) the trading zones of the North American Free Trade Agreement (NAFTA), with a particular focus on the United States, and the EU, (2) China, and (3) Japan and other Asian economies.

The EU, East Asia, and NAFTA have substantial flows of intraregional trade. China’s economy has extensive trade between mainland China and Hong Kong. This section treats trade within these three regions and the economy of China in different ways. Intra-EU and NAFTA exports are not counted because they are integrated trading zones with common external trade tariffs and few restrictions on intraregional trade. Trade between mainland China and Hong Kong is excluded because it is essentially intra-economy trade. (Data on trade in commercial knowledge-intensive services between China and Hong Kong are not available.) Intra-Asian trade is counted for other Asian countries because they have a far smaller degree of political and trade integration.

SIDEBAR

Measurement and Limitations of Trade Data

Trade data are classified by the qualities and characteristics of the products or services themselves, in contrast to industry output data that classify a firm in one industry on the basis of the primary activity of the firm.* Thus, the industry and trade classifications are not compatible with each other and cannot be mapped onto each other. For example, an export classified as a computer service may have originated from a firm that is classified in the computer manufacturing industry because its primary activity is manufacturing computers.

Data on exports and imports represent the market value of products and services in international trade. Exports of products are assigned by the importing country's port of entry to a single country of origin. For goods manufactured in multiple countries, the country of origin is determined by where the product was "substantially transformed" into its final form, which is usually the country of final assembly.

The value of product trade entering or exiting a country's ports may include the value of components, inputs, or services classified in different product categories or originating from countries other than the country of origin. For example, China is credited with the full value (i.e., factory price plus shipping cost) of a smartphone when it is assembled in China, though made with components imported from other countries. In these data, a country whose firms provide high-value services such as design, marketing, and software development for products or services that are produced in a different country are typically not credited for these contributions.

* Traded goods are assigned one product code according to the Harmonized Commodity Description and Coding System, or Harmonized System (HS). HS is used to classify goods traded internationally and was developed under the auspices of the Customs Co-operation Council. Beginning on 1 January 1989, HS numbers replaced schedules previously adhered to in more than 50 countries, including the United States. For more information, see https://www.census.gov/foreign-trade/guide/sec2.html#htsusa.

Global Trade in Commercial Knowledge- and Technology-Intensive Goods and Services

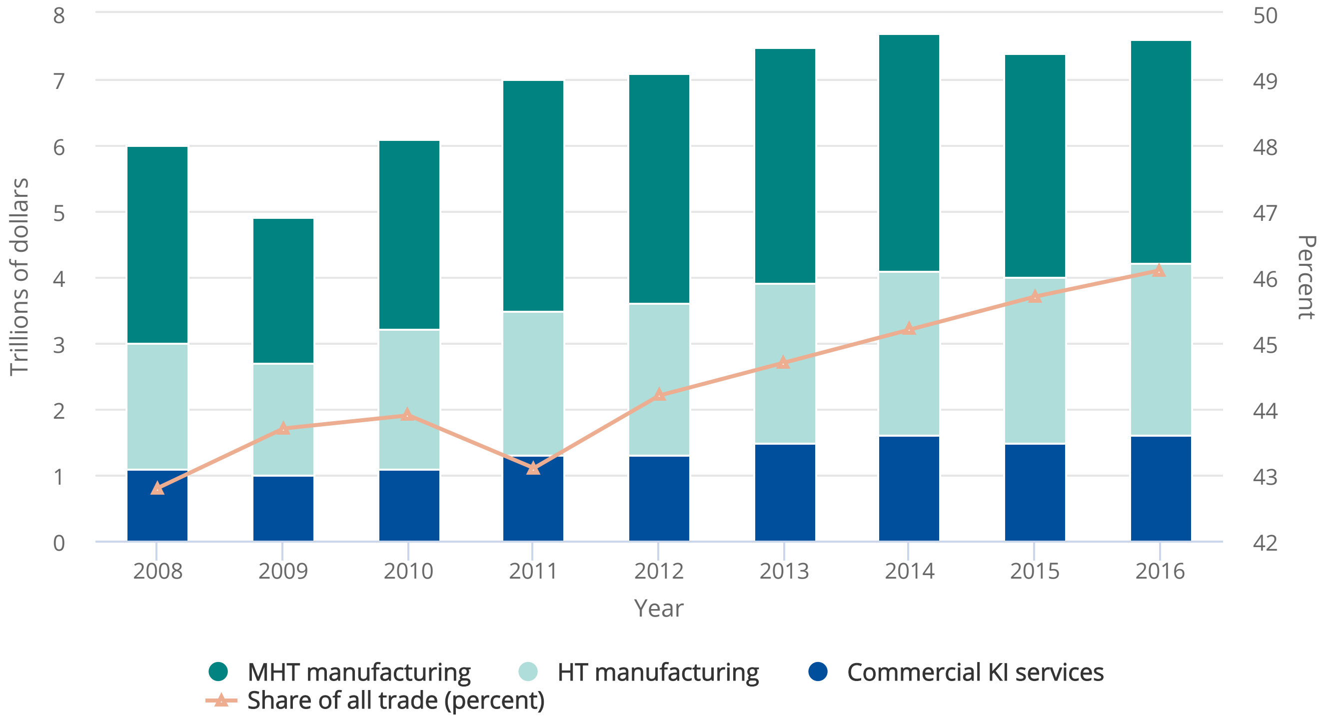
Exported goods and services to other countries are an indicator of a country's economic success in the global market because exports capture the country's products that compete in the world market. In addition, exports bring in income from external sources and do not consume the income of a nation's own residents. However, the use of exports as an indicator of a country's success in global markets has limitations. Exports of goods and services produced in global value chains, including those that have advanced technologies or are knowledge intensive, contain inputs and components supplied by other countries. For example, the value of China's exports of high-technology goods is significantly lower when the foreign content of its exports is excluded (see sidebar Measurement of Trade in Value-Added Terms).

Global trade in commercial KTI goods and services consists of 14 categories. Three categories are knowledge-intensive services—telecommunications, computer, and information; finance; and other business.[1] Eleven are technology-intensive products that consist of six high-technology goods—aerospace; communications; computers; pharmaceuticals; semiconductors; and testing, measuring, and control instruments—and five medium-high-technology goods.

Global exports of commercial KTI goods and services account for 46% of all goods and services exports (Figure 6-21). Global commercial KTI exports were an estimated $7.5 trillion in 2016, consisting of $1.6 trillion of commercial knowledge-intensive services, $2.6 trillion of high-technology products, and $3.4 trillion of medium-high-technology products (Appendix Table 6-25, Appendix Table 6-26, and Appendix Table 6-27).

FIGURE 6-21

Global exports of commercial KTI products and services: 2008–16



HT = high technology; KI = knowledge intensive; KTI = knowledge and technology intensive; MHT = medium-high technology.

Note(s)

Exports of commercial KTI products and services consist of exports of commerical KI services and high technology and medium-high technology manufacturing products. World exports of high technology and medium-high technology exports do not include intra-EU-European Union (EU), intra-North American Free Trade Agreement (NAFTA), and exports betweeen China and Hong Kong. Exports of the EU do not include intra-EU exports. Exports of NAFTA do not include intra-NAFTA exports. Exports of China do not include exports between mainland China and Hong Kong. World exports of commercial KI services consist of other business services; telecommunications and computer and information services; and financial services. Financial services include finance and insurance. World exports and total EU exports of commercial KI services do not include intra-EU trade.

Source(s)

IHS Global Insight, special tabulations of the World Trade Service database (2017) and World Trade Organization, Trade and tariff data. https://www.wto.org/english/res_e/statis_e/statis_e.htm, accessed 15 September 2017. See Appendix Table 6-25, Appendix Table 6-30, and Appendix Table 6-31.

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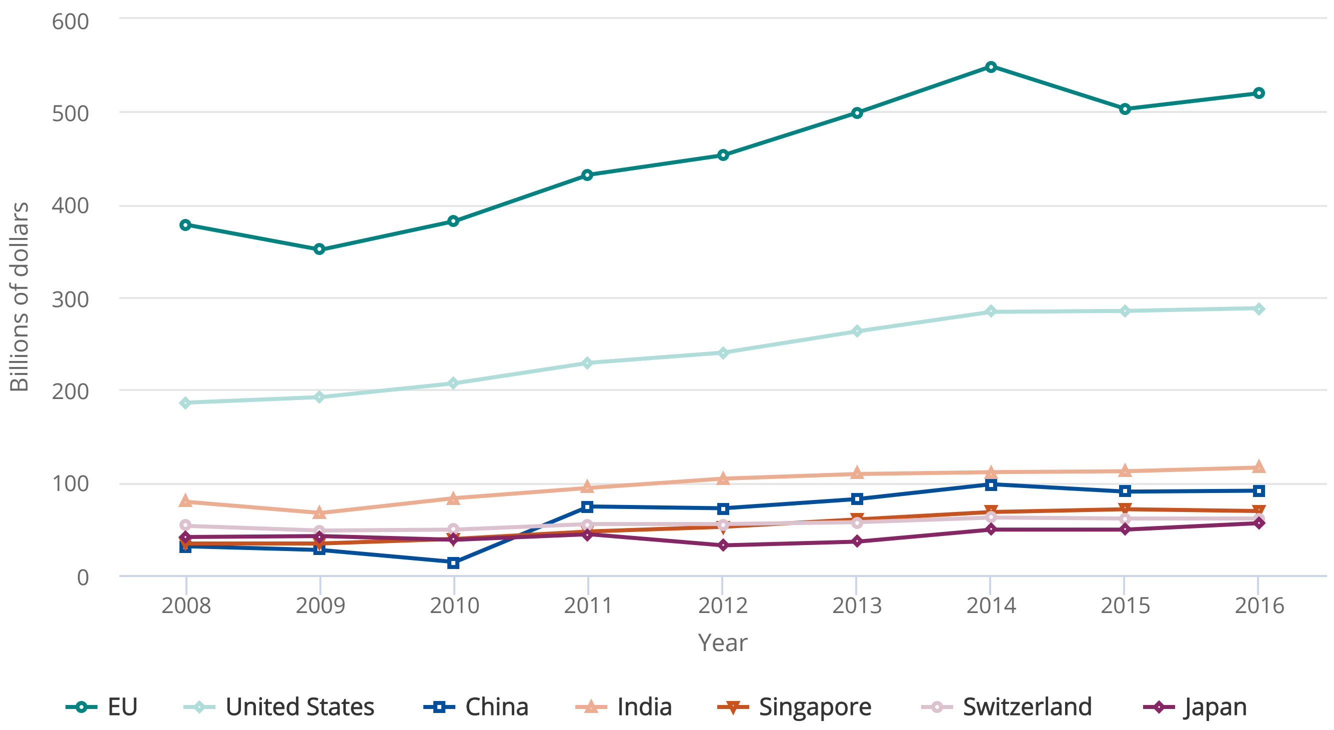
Trade in Commercial Knowledge-Intensive Services

Global exports of commercial knowledge-intensive services make up 43% of all exports of commercial services.[2] Among the commercial knowledge-intensive services, the largest is other business services, which include R&D services, and architectural, engineering, and other technical services ($822 billion) (Appendix Table 6-28).[3] The other two services are finance (which includes insurance and pension) ($399 billion) and telecommunications, computer, and information services ($347 billion) (Appendix Table 6-29 and Appendix Table 6-30).

The EU was the largest exporter of commercial knowledge-intensive services, with a global share of 33% in 2016 (Figure 6-22; Appendix Table 6-25). The United States was the second largest at 18%. Both had substantial surpluses in trade of commercial knowledge-intensive services (Figure 6-23).[4] India is the third largest with a 7% global export share, closely followed by China. Both China and India had surpluses in trade of commercial KI services.

FIGURE 6-22

Commercial KI service exports, by selected region, country, or economy: 2008–16



EU = European Union; KI = knowledge intensive.

Note(s)

Commercial KI service exports consist of communications, business services, financial services, telecommunications, and computer and information services. Financial services include finance, pension, and insurance services. EU exports do not include intra-EU exports.

Source(s)

World Trade Organization, International trade and tariff data, https://www.wto.org/english/res_e/statis_e/statis_e.htm, accessed 15 September 2017.

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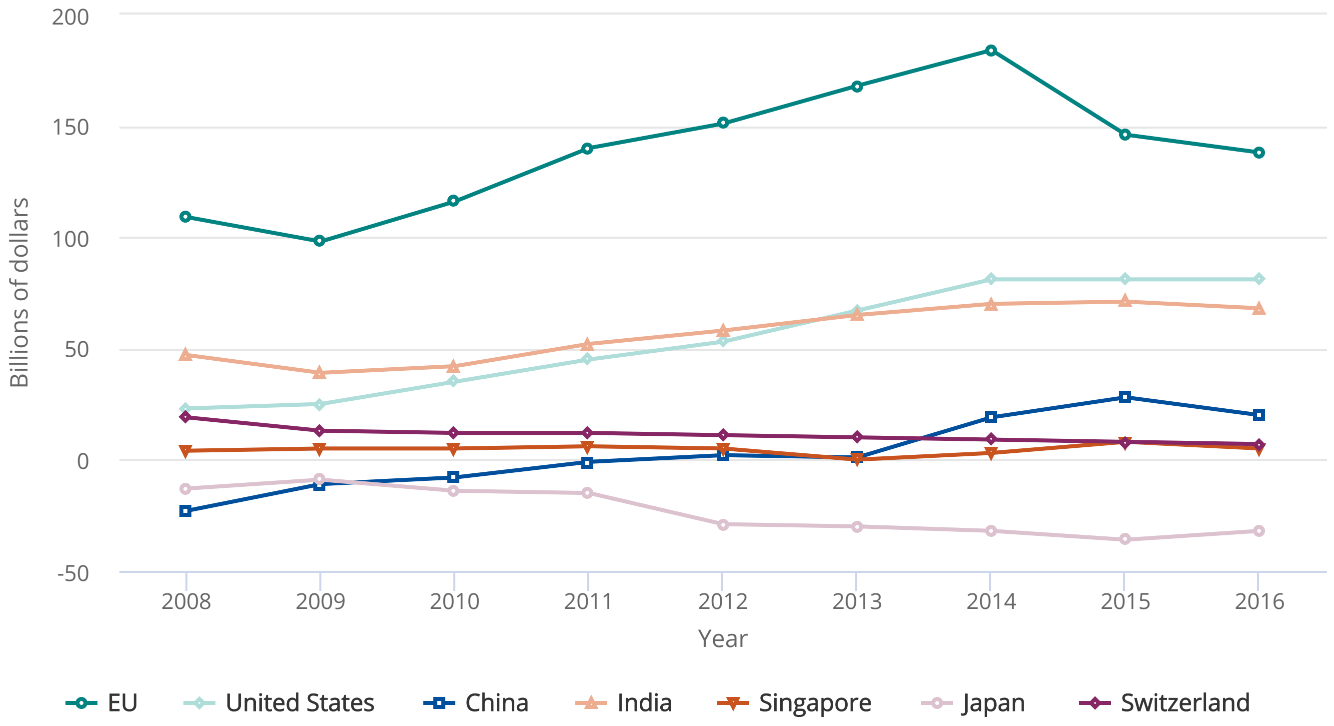
FIGURE 6-23

Trade balance of commercial KI services, by selected region, country, or economy: 2008–16



EU = European Union; KI = knowledge intensive.

Note(s)

Commercial KI service exports consist of communications, business services, financial services, telecommunications, and computer and information services. Financial services include finance, pension, and insurance services. EU exports do not include intra-EU exports.

Source(s)

World Trade Organization, International trade and tariff data, https://www.wto.org/english/res_e/statis_e/statis_e.htm, accessed 15 September 2017.

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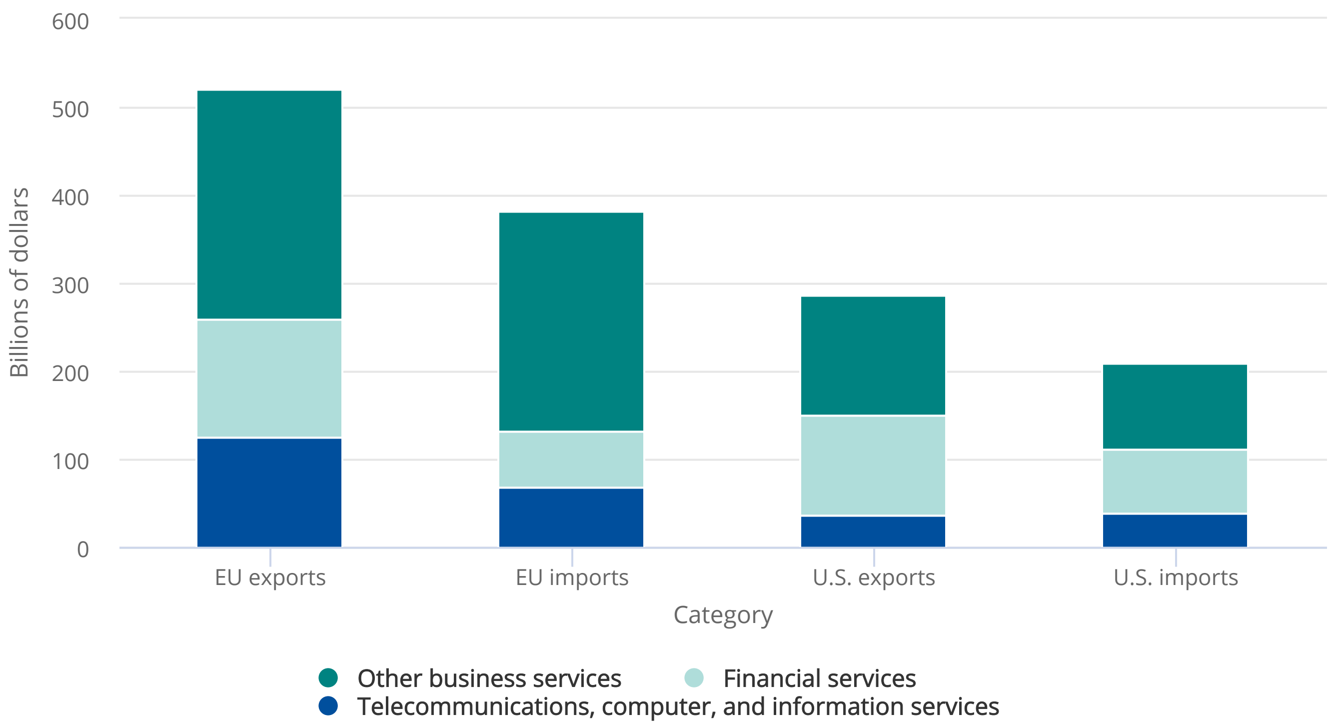
EU Trade in Commercial Knowledge-Intensive Services.

The EU's exports of commercial knowledge-intensive services grew 20% between 2011 and 2016 to reach $520 billion (Figure 6-22; Appendix Table 6-25). Output in the EU's commercial KI industries declined during this period, in sharp contrast to the rise in exports. The euro's substantial depreciation against the dollar, which made EU exports more competitive in global markets, may have contributed to the growth of commercial knowledge-intensive exports (see sidebar Currency Exchange Rates of Major Economies) (Figure 6-6; Appendix Table 6-4). Exports of other business services and telecommunications, computer, and information services drove overall growth, increasing 26% and 29%, respectively, during this period (Appendix Table 6-28 and Appendix Table 6-29). The EU's trade surplus in commercial knowledge-intensive services was $138 billion in 2016, unchanged from its level in 2011 (Figure 6-23 and Figure 6-24; Appendix Table 6-25).

FIGURE 6-24

U.S. and EU commercial KI services trade, by category: 2016



EU = European Union; KI = knowledge intensive.

Note(s)

Commercial KI services trade consists of communications, other business services, financial services, and computer and information services. Financial services include finance and insurance. EU trade does not include intra-EU trade.

Source(s)

World Trade Organization, International trade and tariff data, https://www.wto.org/english/res_e/statis_e/statis_e.htm, accessed 15 January 2017.

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U.S. Trade in Commercial Knowledge-Intensive Services.

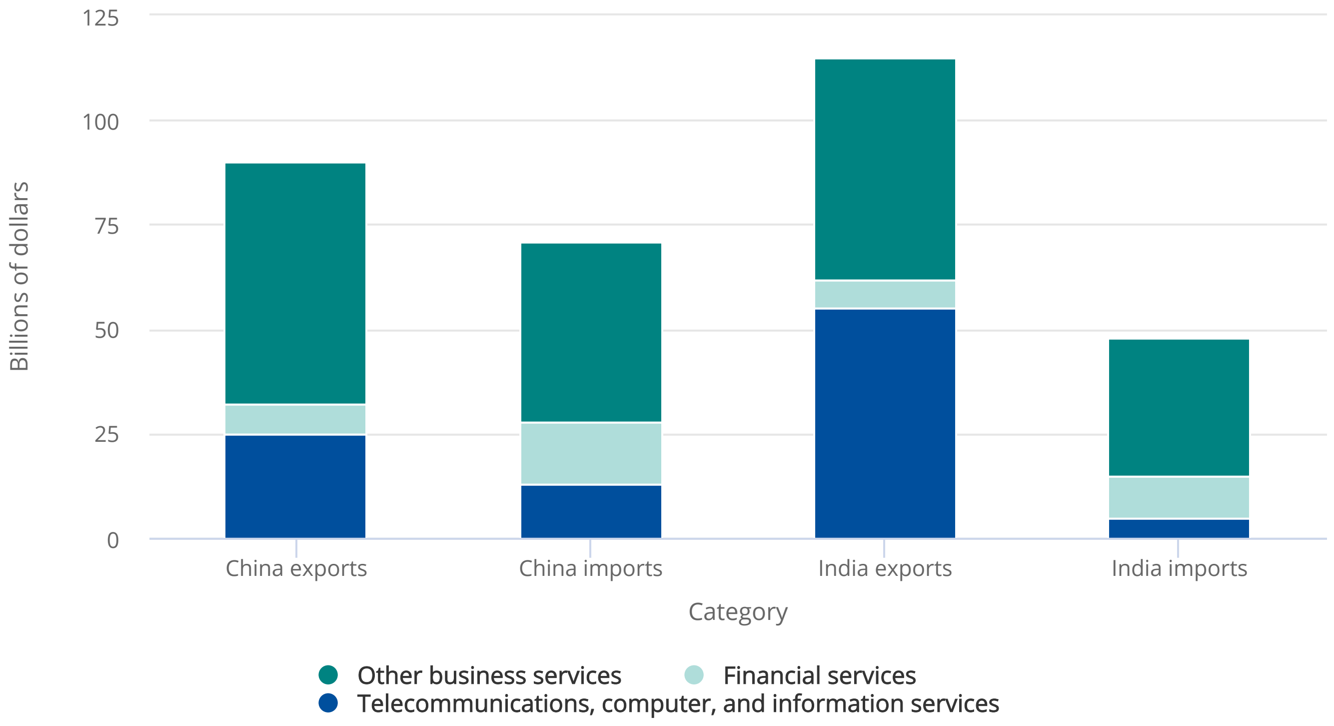
U.S. exports of commercial knowledge-intensive services grew 26% from 2011 to 2016 to reach $288 billion (Figure 6-22; Appendix Table 6-25). The growth of U.S. exports was spurred by growth in other business services (28%) and telecommunications, computer, and information services (28%) (Appendix Table 6-28 and Appendix Table 6-29). The U.S. trade surplus widened from $45 billion to $81 billion, reflecting growing surpluses in other business and financial services (Figure 6-23 and Figure 6-24).

China's and India's Trade in Commercial Knowledge-Intensive Services

China's and India's exports each grew 22% between 2011 and 2016, slightly faster than the EU (Figure 6-22; Appendix Table 6-25). India's growth was led by other business services (38%), coinciding with the Indian firms that provide accounting and other services to firms in developed countries (Appendix Table 6-28). Indian firms also have been very successful in providing IT services to firms in developing countries; India is the world's second largest exporter of telecommunications, computer, and information services (16% global share) (Appendix Table 6-29). India's trade surplus grew from $52 billion to $68 billion from 2011 to 2016 due to the widening of its surplus in other business services and telecommunications, computer, and information services (Figure 6-23 and Figure 6-25).

FIGURE 6-25

China's and India's trade in commercial KI services, by category: 2016



KI = knowledge intensive.

Note(s)

Commercial KI services trade consists of communications, other business services, financial services, and computer and information services. Financial services include finance and insurance.

Source(s)

World Trade Organization, International trade and tariff data, https://www.wto.org/english/res_e/statis_e/statis_e.htm, accessed 15 January 2017.

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China's growth in commercial KI exports was led by a near doubling of its exports of telecommunications, computer, and information services between 2011 and 2016 (Figure 6-22; Appendix Table 6-25 and Appendix Table 6-29). China's global share in telecommunications, computer, and information services edged up from 5% to 7% during this period, coinciding with rapid growth of Chinese firms providing IT services to developed countries, making it the world's fourth largest exporter after India.[5]

Trade in High-Technology Products

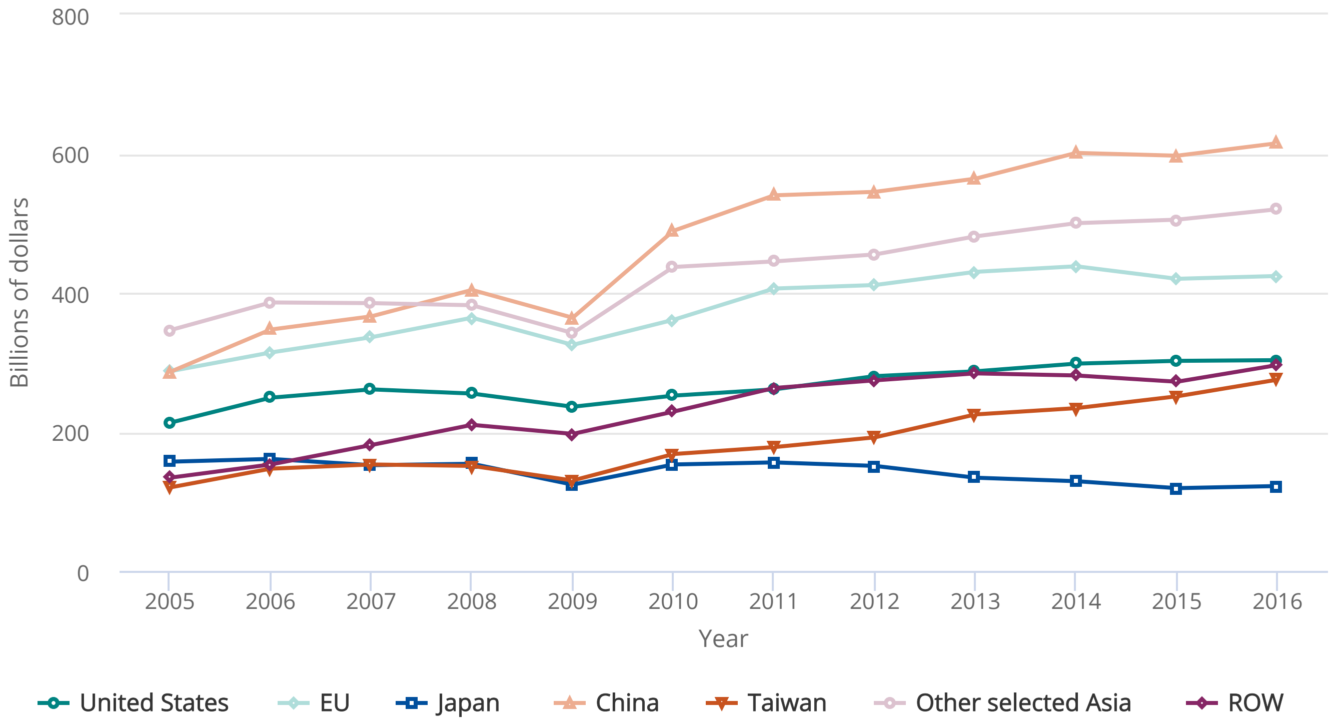
High-technology product exports accounted for 19% of the $13.0 trillion in total manufactured goods exports.[6] The value of global high-technology product exports ($2.6 trillion in 2016) was dominated by ICT products—communications, computers, and semiconductors—with a collective value of $1.4 trillion, more than half of the total in this category (Appendix Table 6-26, and Appendix Table 6-31 through Appendix Table 6-34). Aircraft and spacecraft; pharmaceuticals; and testing, measuring, and control instruments combined added about $1.1 trillion in 2016 (Appendix Table 6-35, Appendix Table 6-36, and Appendix Table 6-37).

China is the world's largest exporter of high-technology goods (24% global share) and has a substantial surplus (Figure 6-26 and Figure 6-27; Appendix Table 6-26). However, because many of China's exports consist of inputs and components imported from other countries, China's exports and trade surplus are likely much less in value-added terms (see sidebar Measurement of Trade in Value-Added Terms).

The EU is the second largest global exporter (17% global share), and its trade position is roughly in balance (Figure 6-26 and Figure 6-27; Appendix Table 6-26). The United States is the third largest exporter (12%) closely followed by Taiwan (11%). The United States has a deficit and Taiwan has a substantial surplus. (For a list of regions and countries and economies in world trade data, see Appendix Table 6-38.)

FIGURE 6-26

Exports of HT products, by selected region, country, or economy: 2005–16



EU = European Union; HT = high technology; ROW = rest of world.

Note(s)

HT products aircraft and spacecraft; communications and semiconductors; computers; pharmaceuticals; and testing, measuring, and control instruments. Data are not available for EU members Cyprus, Estonia, Latvia, Lithuania, Luxembourg, Malta, and Slovenia. China includes Hong Kong. Other selected Asia consists of Indonesia, Malaysia, Philippines, Singapore, South Korea, Thailand, Taiwan, and Vietnam. Exports of the United States exclude exports to Canada and Mexico. Exports of the EU exclude intra-EU exports. Exports of China exclude exports between China and Hong Kong.

Source(s)

IHS Global Insight, World Trade Service database (2018). See Appendix Table 6-20.

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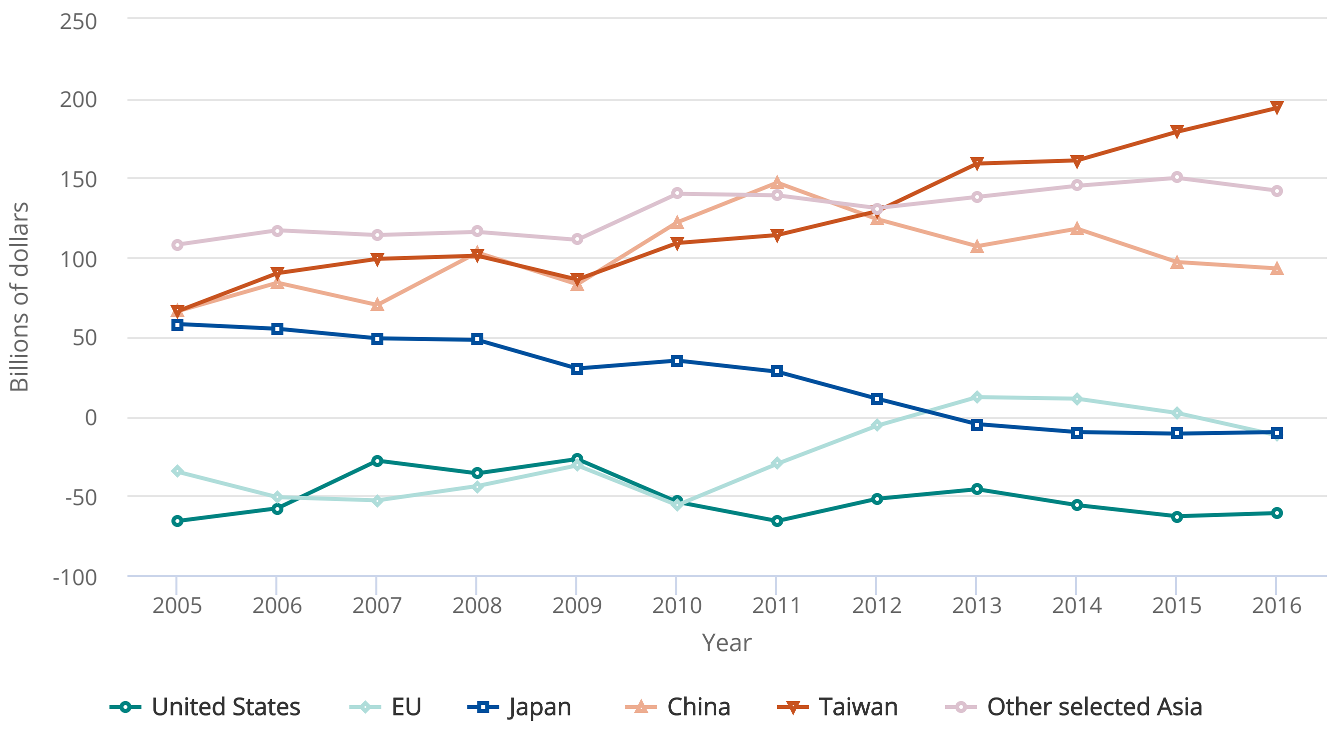
FIGURE 6-27

Trade balance of HT products, by selected region, country, or economy: 2005–16



EU = European Union; HT = high technology.

Note(s)

HT products include aircraft and spacecraft; communications and semiconductors; computers; pharmaceuticals; and testing, measuring, and control instruments. Data are not available for EU members Cyprus, Estonia, Latvia, Lithuania, Luxembourg, Malta, and Slovenia. China includes Hong Kong. Other selected Asia consists of Malaysia, Philippines, Singapore, South Korea, Thailand, Taiwan, and Vietnam. Exports and imports of the United States exclude exports to Canada and Mexico. Exports and imports of the EU exclude intra-EU exports. Exports and imports of China exclude exports between China and Hong Kong.

Source(s)

IHS Global Insight, World Trade Service database (2017). See Appendix Table 6-20.

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China's Trade in High-Technology Goods

Between 2011 and 2016, China's high-technology exports grew 14% to reach $615 billion, and the trade surplus fell from $147 billion to $93 billion (Figure 6-26 and Figure 6-27; Appendix Table 6-26). Growth of China's high-technology products exports has slowed sharply in the post-global recession period. Exports grew at an annualized average of 3% between 2011 and 2016, compared to 24% between 2001 and 2008. China's slowdown in high-technology exports reflects the cooling-off of China's economic growth and sluggish export demand by the EU, Japan, and large developing countries that have had slow or negative economic growth. China's global share stayed stable at 24% in the post-global recession period after increasing rapidly in the prior decade.

China's ICT exports also grew at a much slower rate in the post-global recession period than prior to the recession (Appendix Table 6-31 through Appendix Table 6-34). China's ICT exports dominate its high-technology exports, and China is the world's largest exporter of ICT products (Appendix Table 6-31). China's ICT trade surplus slightly narrowed to reach $153 billion during this period.

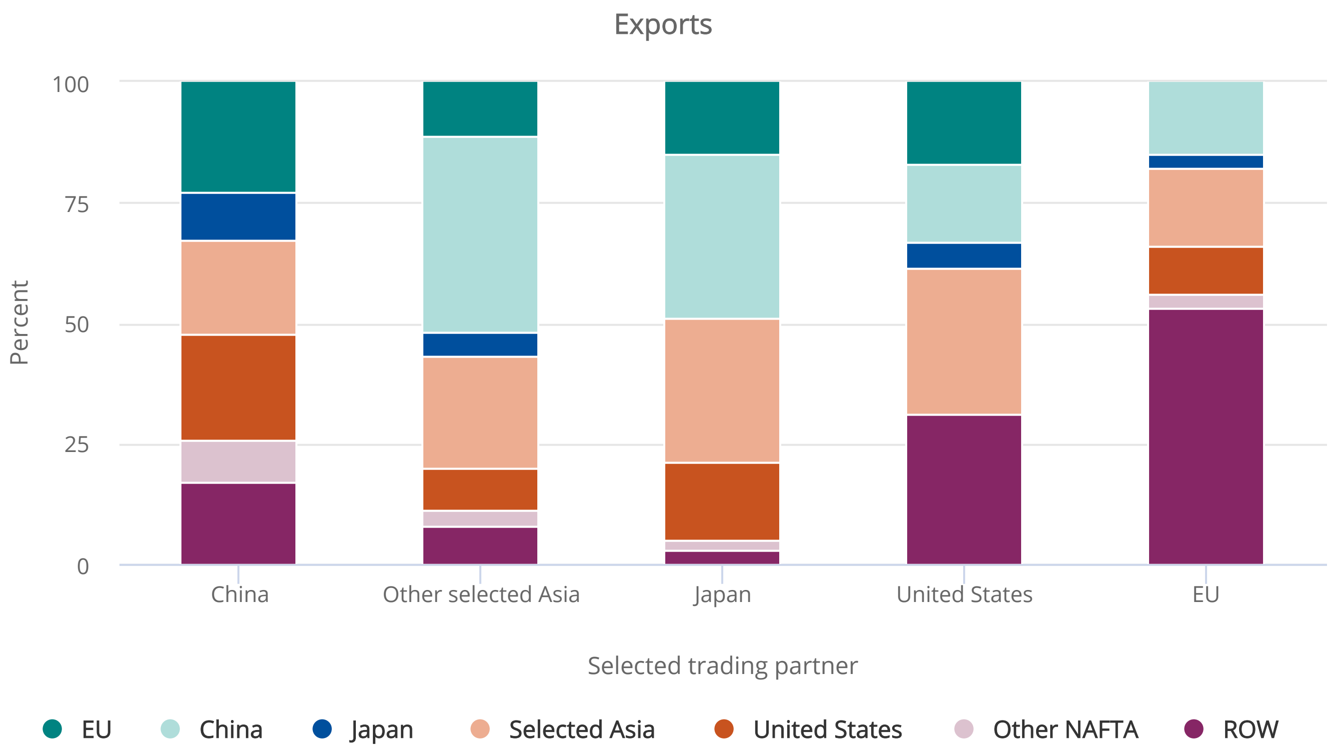
China is the hub of "Factory Asia," which produces much of the world's ICT products. The patterns of China's trade with its major partners shows its integration with other Asian producers that supply components and parts (📊Figure 6-28). Imports from eight Asian economies—Indonesia, Malaysia, Philippines, Singapore, South Korea, Taiwan, Thailand, and Vietnam—account for three-quarters of China's ICT imports. However, conventional trade statistics do not measure the contribution by countries that produce ICT and other products in global value chains. Data on value-added trade, which estimates the contribution of countries for goods produced in global value chains, suggest that the United States, the EU, South Korea, and Taiwan are a significant source of China's imports of ICT goods in the form of inputs and components (see sidebar 💬Measurement of Trade in Value-Added Terms).

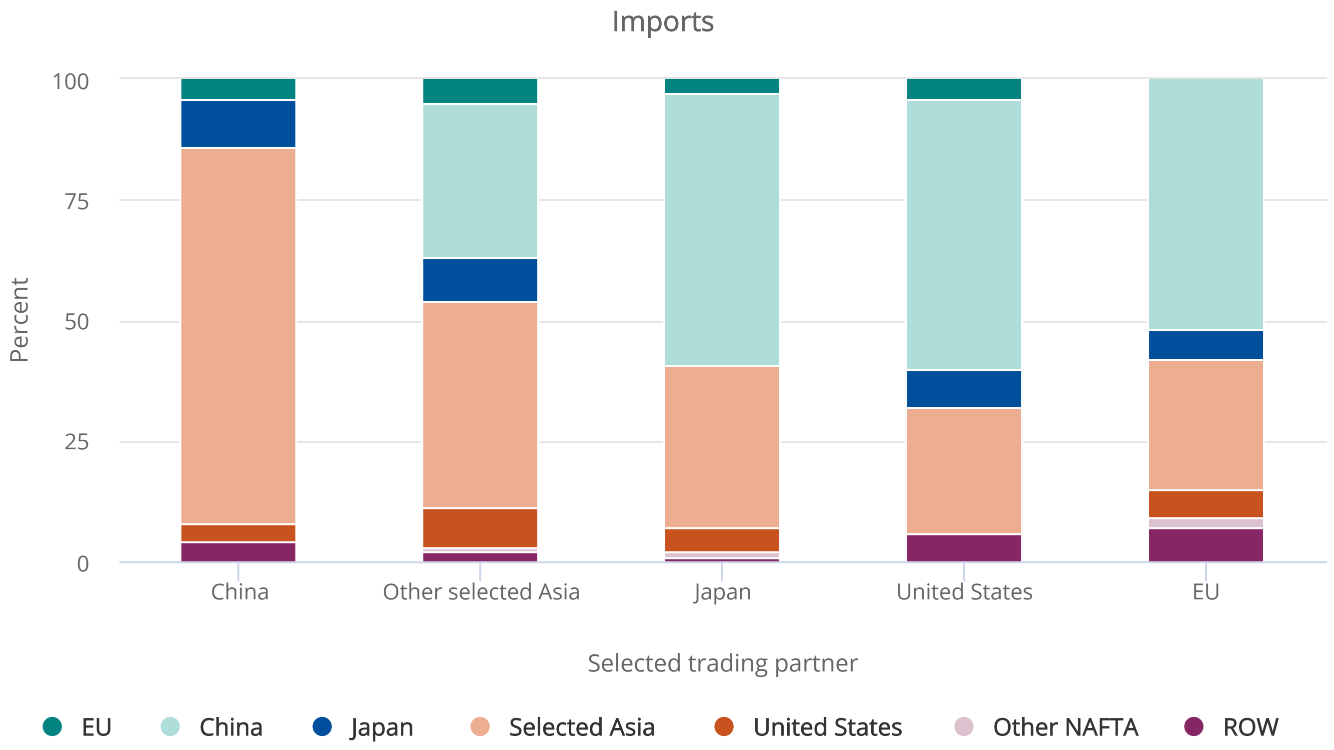
More than half of China's ICT exports are destined for the three major developed economies—the EU (23%), the United States (22%), and Japan (10%). China's export share with the eight Asian economies is 20%, far less than its import share (📊Figure 6-28).

China's exports of testing, measuring, and control instruments grew more than twice as fast (30%) as its ICT exports between 2011 and 2016 to reach $72 billion (Appendix Table 6-31 and Appendix Table 6-35).

FIGURE 6-28

Trade in ICT products of selected regions, countries, or economies, by selected trading partner: 2016





EU = European Union; ICT = information and communications technology; NAFTA = North American Free Trade Agreement; ROW = rest of world.

Note(s)

ICT products include communications, semiconductors, and computers and office machinery. The EU excludes Cyprus, Estonia, Latvia, Lithuania, Luxembourg, Malta, and Slovenia. China includes Hong Kong. Other selected Asia includes Indonesia, Malaysia, Philippines, Singapore, South Korea, Taiwan, Thailand, and Vietnam.

Source(s)

IHS Global Insight, World Trade Service database (2016). See Appendix Table 6-20.

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EU Trade in High-Technology Goods

The EU's high-technology exports edged up 5% between 2011 and 2016, with the EU's global share remaining stable at 17%–18% (Figure 6-26; Appendix Table 6-26). Output of the EU's high-technology manufacturing industries increased slightly during this period, in contrast to growth in exports (Figure 6-11). The euro's substantial depreciation against the dollar, which made EU exports more competitive in global markets, among other things, may have contributed to the growth of exports (see sidebar Currency Exchange Rates of Major Economies) (Figure 6-11; Appendix Table 6-8). Aircraft and pharmaceuticals grew the fastest, driving the growth of the EU's high-technology exports (Appendix Table 6-36 and Appendix Table 6-37). The EU is the world's largest exporter of pharmaceuticals, and its global share remained roughly stable at 44%–46% in the post-global recession period (Appendix Table 6-36). The EU's trade surplus in pharmaceuticals slightly increased during this period. The EU is the world's second largest exporter in aircraft; the EU's global share slid from 39% to 32% (Appendix Table 6-37). The

EU's trade surplus slightly narrowed during this period. Exports of ICT products declined sharply (25%), and the EU's global share dropped from 7% to 5% (Appendix Table 6-31 through Appendix Table 6-34).

U.S. Trade in High-Technology Goods

U.S. high-technology product exports grew 16% in the post-global recession period, with the U.S. global share remaining stable at 12% (Figure 6-26; Appendix Table 6-26). The U.S. trade deficit remained in a range of $46–$66 billion (Figure 6-27).[7] Aircraft drove overall export growth, increasing by 52% (Appendix Table 6-37). Exports of aircraft climbed to $130 billion, and the related trade surplus widened from $57 billion to $89 billion. The United States maintained its dominance as the world's largest exporter of aircraft (43% global share). Pharmaceutical exports reached $50 billion, and the deficit widened from $26 billion to $45 billion (Appendix Table 6-36).

ICT product exports declined by 13% to reach $64 billion between 2011 and 2016, with the U.S. global share declining from 6% to 4% (Appendix Table 6-31 through Appendix Table 6-34). Much of the U.S. trade deficit in ICT products ($106 billion) is with China; more than half of U.S. imports are from China, while China has a far smaller share of U.S. ICT exports (Figure 6-28). However, conventional trade statistics attribute the substantial foreign content as part of the value of China's ICT exports. The United States and other countries export sophisticated ICT inputs and components to China and other Asian economies, and they are then assembled in China. For example, the United States exports slightly half of its total ICT exports to Asian economies involved in ICT production and trade, including China (16%), Japan (5%), and eight other Asian economies —Indonesia, Malaysia, Philippines, Singapore, South Korea, Taiwan, Thailand, and Vietnam (30%) (Figure 6-28). Some of the U.S. ICT exports to other Asian economies likely end up in China. The United States likely has higher exports and a lower trade deficit on value-added terms, which attributes the U.S. content embodied in exports by China and other countries to the value of U.S. exports (see sidebar Measurement of Trade in Value-Added Terms).

High-Technology Goods Trade of Other Countries

Taiwan's high-technology exports grew by more than 50% during the post-global recession period, reaching $275 billion (Figure 6-26; Appendix Table 6-26). Taiwan's global share rose from 8% to 11% to nearly reach the level of the United States. Taiwan's rapid gains in high-technology exports were due to growth of ICT product exports (56%), which reached $238 billion (Appendix Table 6-31 through Appendix Table 6-34). Taiwan is the world's second largest exporter of ICT products (17% global share) behind China (Appendix Table 6-31).

Vietnam's exports grew the fastest of any country, with its high-technology exports increasing nearly five-fold to reach $63 billion (Appendix Table 6-26). ICT exports, which comprise nearly all of Vietnam's high-technology exports, reached $61 billion (Appendix Table 6-31 through Appendix Table 6-34). Vietnam has become a low-cost location for assembly of cell phones and other ICT products, with some firms shifting production out of China, where labor costs are higher.[8]

India's exports grew 38% between 2011 and 2016 to reach $31 billion. Exports of pharmaceuticals grew by 61% to reach $19 billion (Appendix Table 6-36). India and China are the largest exporters of pharmaceutical goods among developing countries, with a 5% and 4% global share, respectively.

SIDEBAR

Measurement of Trade in Value-Added Terms

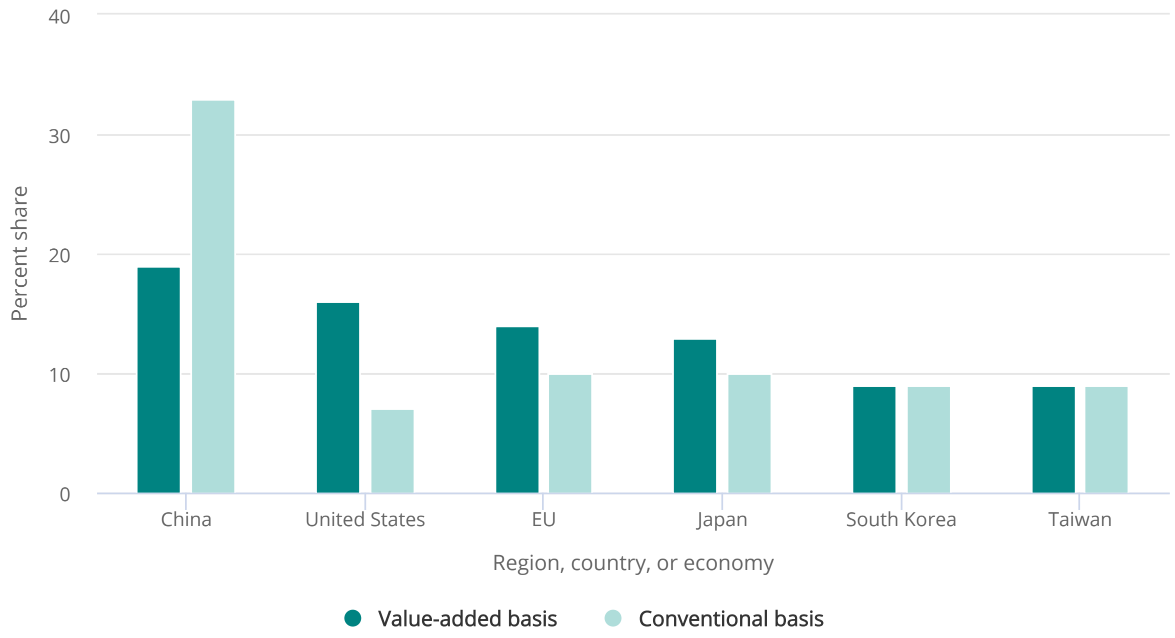
Manufactured goods increasingly embody elements produced by global supply chains, and the conventional trade measures reported throughout this chapter count the gross value of both intermediate and final goods upon crossing international borders. The Trade in Value Added joint initiative of the Organisation for Economic Co-operation and Development (OECD) and the World Trade Organization (WTO) aims to correct this shortcoming by recording only net value added at each crossing. This approach has two advantages: First, it provides more accurate measures of the value of global trade; and second, it enables better estimates of national contributions to the value of goods and services—their value-added—in international trade.

Although it does not cover all six high-technology goods, the OECD/WTO database has value-added and conventional data on the computer, electrical, and optical equipment category. This category is roughly equivalent to four of the six products classified as high technology—communications, computers, semiconductors, and scientific measuring instruments. These industries are most often produced in complex and dispersed global supply chains across multiple countries. Foreign content accounted for 42% of global exports of optical and electrical equipment in 2011, the highest share among the OECD/WTO classified manufacturing industries.*

The OECD/WTO data suggest that China has a weaker position in trade of computer, electrical, and optical equipment on a value-added basis compared to a conventional basis. China is the world's largest exporter (33% global share) on a conventional basis, with a wide lead over the EU, the United States, Japan, South Korea, and Taiwan (Figure 6-E). Although it continues to be the largest global exporter on a value-added basis, China's global share is comparatively lower (19%), and its lead over the United States and other major exporters is far narrower. The large decline of China's global share moving from a conventional to a value-added basis is due to the high share of foreign content in China's exports. The value-added measurement of China's exports attributes the foreign content of China's exports to the countries that supplied the components. These countries include the EU, the United States, Japan, and other Asian countries.

FIGURE 6-E

Exports of computer, electrical, and optical equipment, by selected region, country, or economy on conventional and value-added basis: 2011



EU = European Union.

Note(s)

Exports measured on a conventional basis are based on customs data and include intermediate inputs and components imported from other countries. Exports measured on a value-added basis estimate the value added of inputs and components originating from the region, country, or economy and exclude intermediate inputs and components imported from other countries. The EU includes the current 28 member countries. EU exports exclude exports among EU member countries. China includes Hong Kong. China's exports exclude exports between China and Hong Kong. U.S. exports exclude exports to Canada and Mexico.

Source(s)

Organisation for Economic Co-operation and Development, Trade in Value Added Database, https://stats.oecd.org/Index.aspx?DataSetCode=TIVA2015_C1, accessed 3 November 2017.

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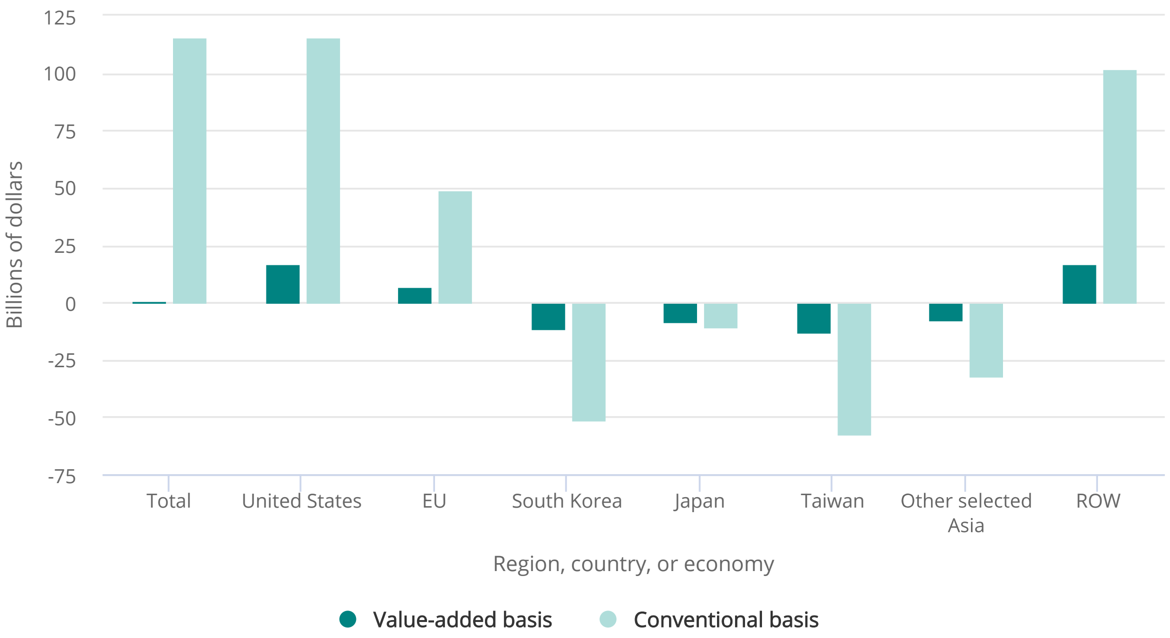
In addition to a smaller global export share, China’s trade surplus shrank from $120 billion on a conventional basis in 2011 to $1 billion on a value-added basis (Figure 6-F). The decline in China’s overall trade surplus is largely due to a sharp fall in its bilateral surplus with the United States, which declined from nearly $120 billion to under $20 billion. The decline in China’s trade surplus with the United States was mainly due to increases in imports from the United States, which rose from 6% of total imports on a conventional basis to 13% on a value-added basis. This suggests that China’s imports contain inputs and components supplied by the United States that are credited to the United States when utilizing the value-added basis. China's trade deficits with South Korea and Taiwan fell, coinciding with a decline in their share of China's total imports.

FIGURE 6-F

China's trade balance in the electrical and optical equipment industry, by selected region, country, or economy on conventional and value-added basis: 2011



EU = European Union; ROW = rest of world.

Note(s)

Exports and imports measured on a conventional basis are based on customs data and include intermediate inputs and components imported from other countries. Exports and imports measured on a value added basis estimate the value added of inputs and components originating from the region, country, or economy and exclude intermediate inputs and components imported from other countries. The EU includes the current 28 member countries. EU exports exclude exports and imports among EU member countries. China includes Hong Kong. China's exports and imports exclude exports and imports between China and Hong Kong. U.S. exports and imports exclude exports and imports to Canada and Mexico. Other selected Asia includes India, Indonesia, Malaysia, Philippines, Singapore, Thailand, and Vietnam.

Source(s)

Organisation for Economic Co-operation and Development, Trade in Value Added Database, https://stats.oecd.org/Index.aspx?DataSetCode=TIVA2015_C1, accessed 3 November 2017.

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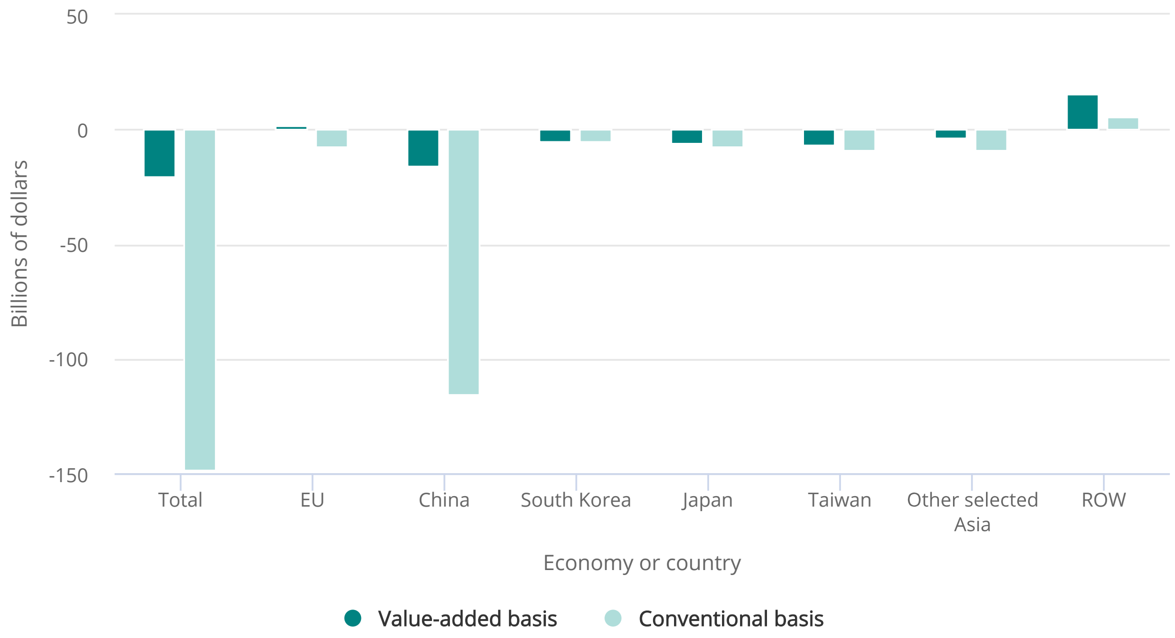
The United States had a comparatively stronger trading position on a value-added basis compared to a conventional basis. On a conventional basis, the United States was tied with Japan, South Korea, and Taiwan as the world's third-largest exporter (7% global share), and is far below China (Figure 6-E). On a value-added basis, the U.S. export share jumped to 16%, making it the world's second-largest exporter, with a far narrower gap with first-ranked China. Measuring U.S. exports on a value-added basis credited the United States for the exports of inputs and components to China and other countries, which were credited to the location of final assembly on a conventional basis.

The higher U.S. global export share on a value-added basis coincides with a much narrower U.S. trade deficit, which dropped from nearly $150 billion on a conventional basis to $21 billion on a value-added basis (Figure 6-G). The narrower trade deficit is largely due to a much smaller bilateral trade deficit with China. The improvement in the bilateral deficit is primarily due to lower Chinese imports, which declined from about half of total U.S. imports on a conventional basis to 30% on a value-added basis. The import shares of Japan, South Korea, and Taiwan, which are major suppliers of inputs to China, rose from a collective share of 17% to 33% of total U.S. imports, suggesting that these three economies were exporting intermediate inputs to the United States that were then further processed and exported to China.

FIGURE 6-G

U.S. trade balance in the electrical and optical equipment industry, by selected country or economy on conventional and value-added basis: 2011



EU = European Union; ROW = rest of world.

Note(s)

Exports and imports measured on a conventional basis are based on customs data and include intermediate inputs and components from other countries. Exports and imports measured on a value added basis estimate the value added of inputs and components originating from the region, country, or economy and exclude imports of inputs and components from other countries. The EU includes the current 28 member countries. EU exports exclude exports and imports among EU member countries. China includes Hong Kong. China's exports and imports exclude exports and imports between China and Hong Kong. U.S. exports and imports exclude exports and imports to Canada and Mexico. Other selected Asia includes India, Indonesia, Malaysia, Philippines, Thailand, and Vietnam.

Source(s)

Organisation for Economic Co-operation and Development, Trade in Value Added Database, https://stats.oecd.org/Index.aspx?DataSetCode=TIVA2015_C1, accessed 3 November 2017.

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Data on the OECD/WTO trade in value-added indicators and additional information are available at https://www.oecd.org/industry/ind/measuringtradeinvalue-addedanoecd-wtojointinitiative.htm.

* OECD, Trade in Value Added Database, October 2015 http://stats.oecd.org/Index.aspx?DataSetCode=TIVA2015_C1.

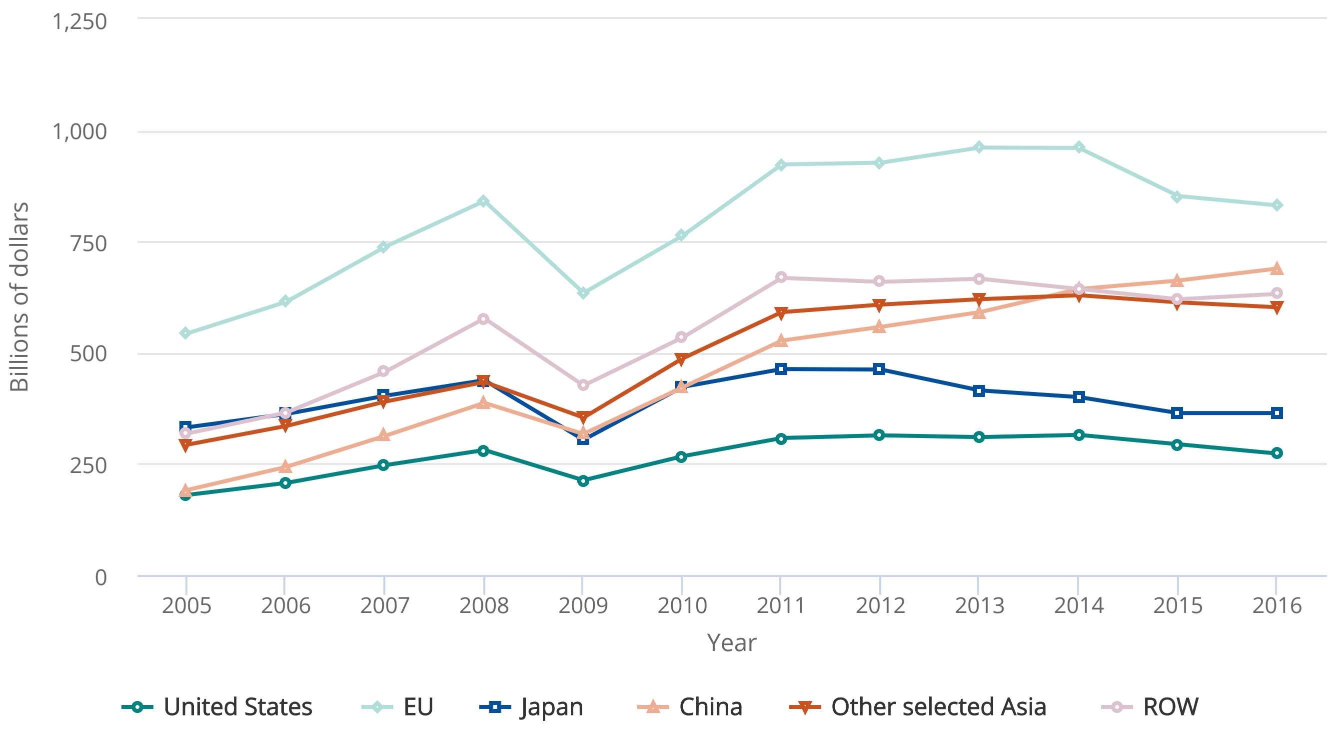
Medium-High-Technology Products

Medium-high-technology product exports accounted for 25% of the $13.0 trillion in total manufactured goods exports.[9] Global medium-high-technology product export value ($3.4 trillion in 2016 measured conventionally at port of entry) was dominated by three products—chemicals excluding pharmaceuticals ($1.2 trillion), machinery and equipment ($1.0 trillion), and motor vehicles and parts ($0.7 trillion) (Figure 6-29; Appendix Table 6-27, Appendix Table 6-39, Appendix Table 6-40, and Appendix Table 6-41). Electrical equipment and appliances added $0.5 trillion, and railroad and other transportation accounted for $24 billion (Appendix Table 6-42 and Appendix Table 6-43).

The EU is the world's largest exporter of medium-high-technology goods (25% global share). China, the second largest global exporter with a 20% global share, also has a substantial trade surplus, as does Japan (11% global share) (Figure 6-29 and Figure 6-30; Appendix Table 6-27). In contrast, the United States, the fourth largest exporter (8% global share), has a substantial deficit ($225 billion). For a list of regions and countries/economies in world trade data, see Appendix Table 6-38.

FIGURE 6-29

Exports of MHT products, by selected region, country, or economy: 2005–16



EU = European Union; MHT = medium-high technology; ROW = rest of world.

Note(s)

MHT products include motor vehicles and parts, electrical machinery, machinery and equipment, chemicals excluding pharmaceuticals, and railroad and other transportation equipment. Data are not available for EU members Cyprus, Estonia, Latvia, Lithuania, Luxembourg, Malta, and Slovenia. China includes Hong Kong. Other selected Asia consists of Indonesia, Malaysia, Philippines, Singapore, South Korea, Taiwan, Thailand, and Vietnam. Exports of the United States exclude exports to Canada and Mexico. Exports of the EU exclude intra-EU exports. Exports of China exclude exports between China and Hong Kong.

Source(s)

IHS Global Insight, World Trade Service database (2017). See Appendix Table 6-20.

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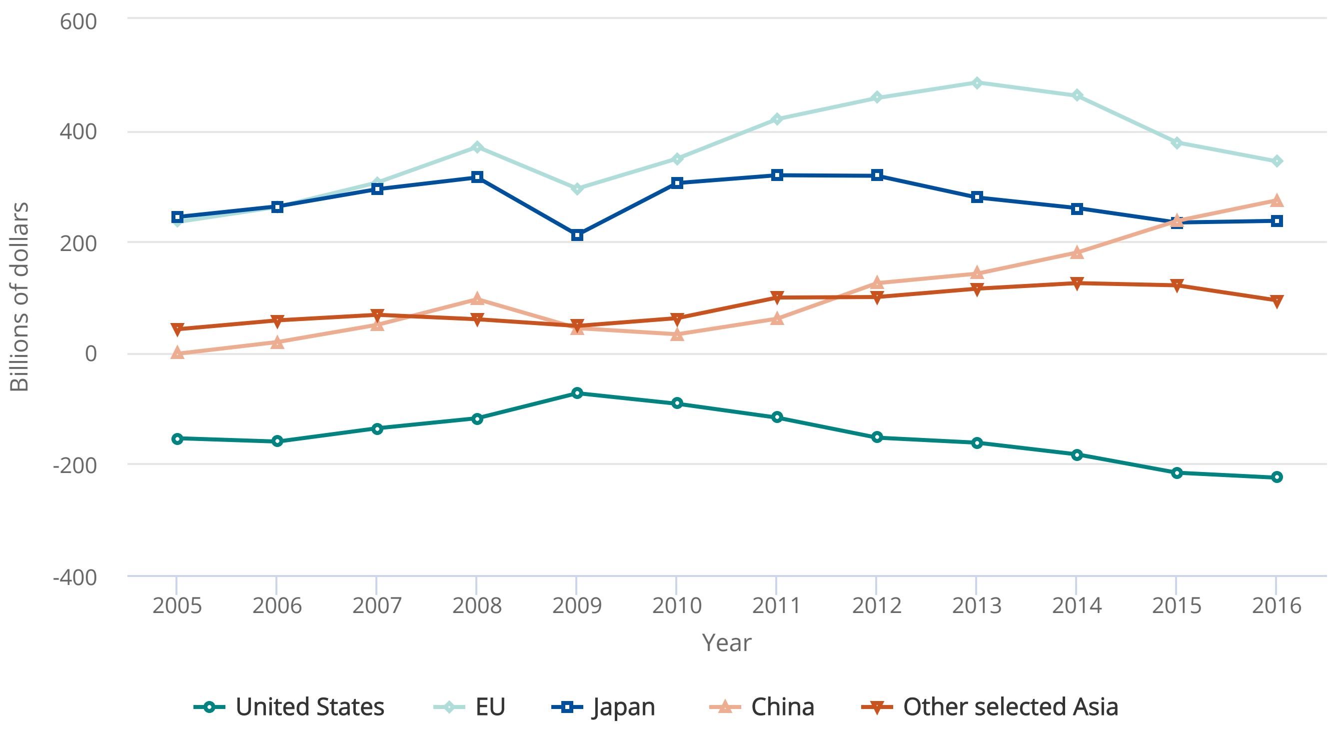
FIGURE 6-30

Trade balance of MHT products, by selected region, country, or economy: 2005–16



EU = European Union; MHT = medium-high technology.

Note(s)

MHT products include motor vehicles and parts, electrical machinery, machinery and equipment, chemicals excluding pharmaceuticals, and railroad and other transportation equipment. Data are not available for EU members Cyprus, Estonia, Latvia, Lithuania, Luxembourg, Malta, and Slovenia. China includes Hong Kong. Other selected Asia consists of Indonesia, Malaysia, Philippines, Singapore, South Korea, Taiwan, Thailand, and Vietnam. Exports and imports of the United States exclude exports to Canada and Mexico. Exports and imports of the EU exclude intra-EU exports. Exports and imports of China exclude exports between China and Hong Kong.

Source(s)

IHS Global Insight, World Trade Service database (2017). See Appendix Table 6-20.

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EU Trade in Medium-High-Technology Goods

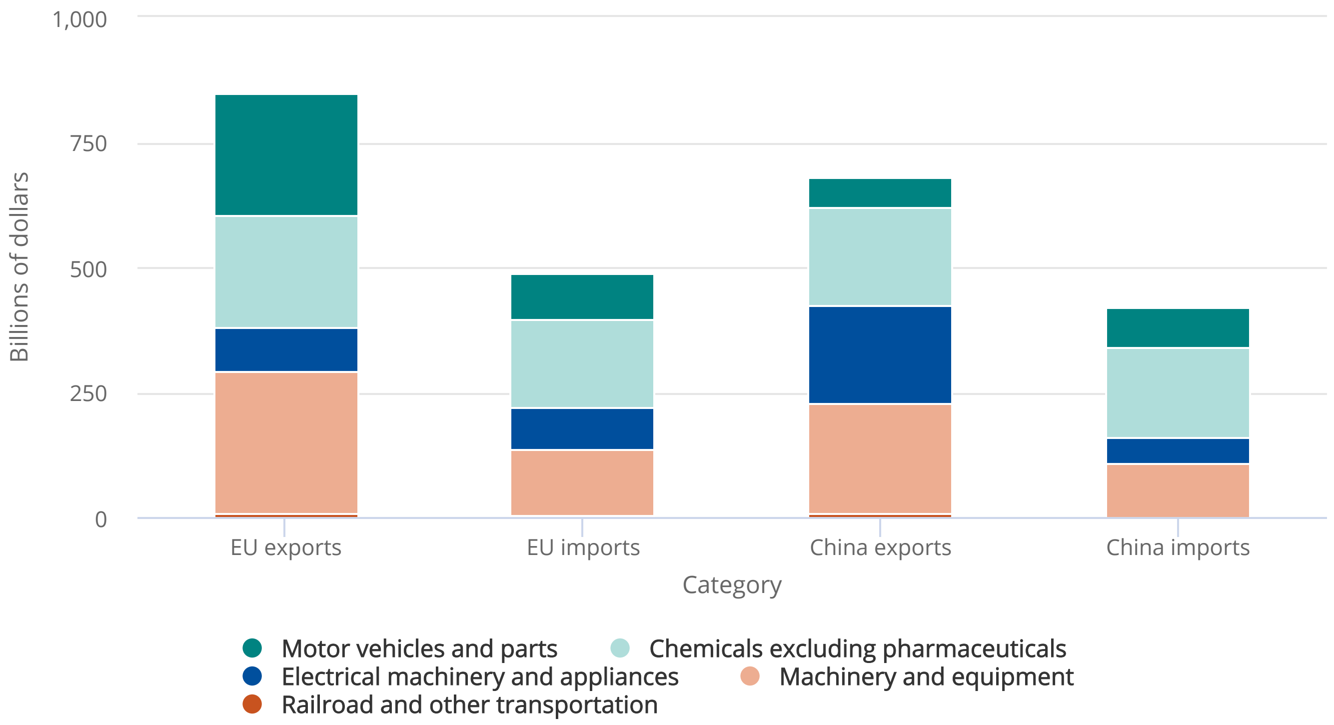
The EU's medium-high-technology exports fell 10% between 2011 and 2016, with its trade surplus falling from $420 billion to $344 billion (Figure 6-29, Figure 6-30, and Figure 6-31; Appendix Table 6-27).

Exports of chemicals excluding pharmaceuticals, machinery and equipment, and electrical equipment and appliances each fell by 9%–13% during this period (Appendix Table 6-40, Appendix Table 6-41, and Appendix Table 6-42). The EU is the world's largest exporter of chemicals excluding pharmaceuticals and machinery and equipment. The EU's global share stayed stable in chemicals excluding pharmaceuticals (19%–20%) and fell slightly in machinery and equipment to reach 29%. The trade surplus in machinery and equipment fell from $190 billion to $152 billion.

Exports of motor vehicles and parts were stagnant during this period (Appendix Table 6-39). The EU is the world's largest exporter of motor vehicles and parts, excluding the considerable amount of intra-EU exports (34% global share). The considerable value of intra-EU trade in this industry suggests that much of the inputs, components, and final assembly is located in the EU and that many EU-produced cars and trucks are sold within the EU.[10] The United States and China are major export markets for the EU.

FIGURE 6-31

China and EU MHT trade, by product: 2016



EU = European Union; MHT = medium-high technology.

Note(s)

MHT products include motor vehicles and parts, electrical machinery, machinery and equipment, chemicals excluding pharmaceuticals, and railroad and other transportation equipment. China includes Hong Kong. Data are not available for EU members Cyprus, Estonia, Latvia, Lithuania, Luxembourg, Malta, and Slovenia. Exports and imports of China exclude exports between China and Hong Kong. Exports and imports of the EU exclude intra-EU exports.

Source(s)

IHS Global Insight, World Trade Service database (2017). See Appendix Table 6-20.

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China's Trade in Medium-High-Technology Goods

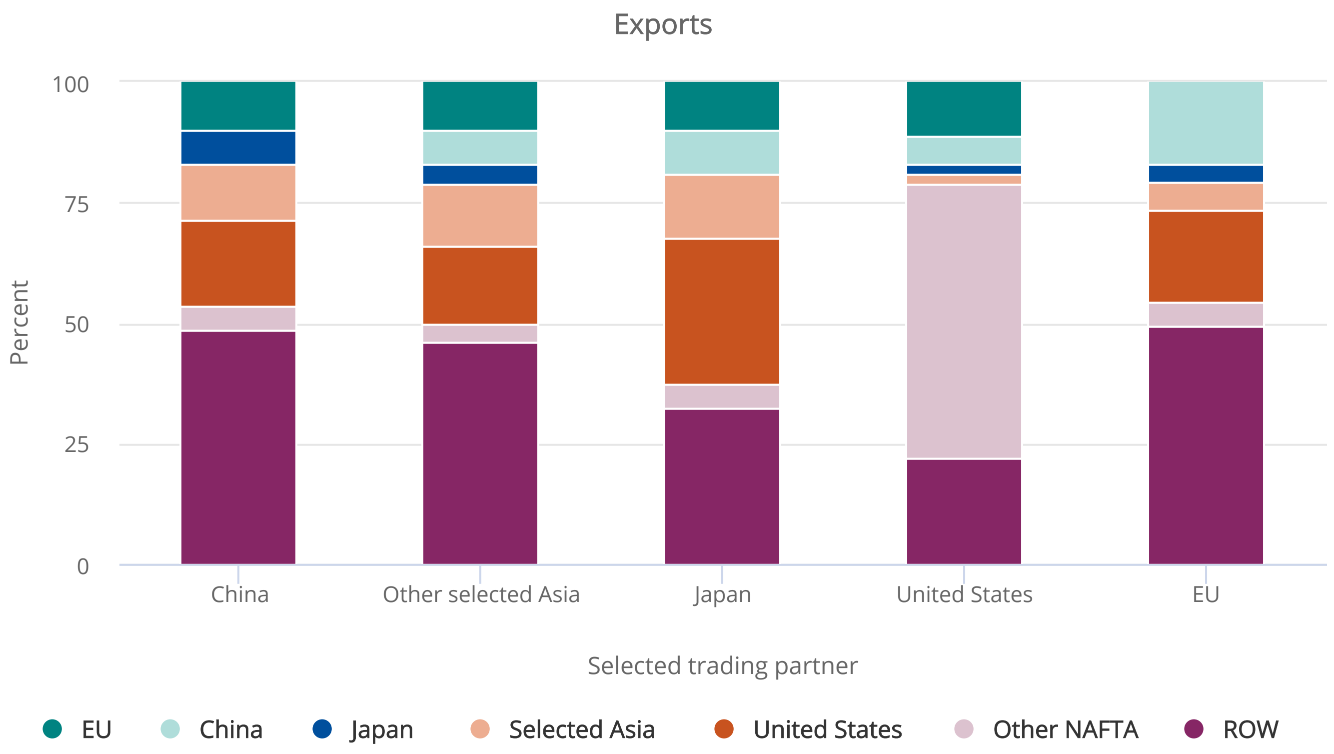
China was the only major economy whose exports of medium-high-technology expanded between 2011 and 2016, reaching $689 billion, a 31% increase (Figure 6-29; Appendix Table 6-27). China's trade surplus widened from $61 billion to $274 billion (Figure 6-30 and Figure 6-31). Over the last decade, China's exports have nearly tripled, and China's global share has climbed from 11% to 20%. China surpassed Japan in 2011 to become the world's second largest exporter, and its gap with the EU, the world's largest exporter, has narrowed considerably.

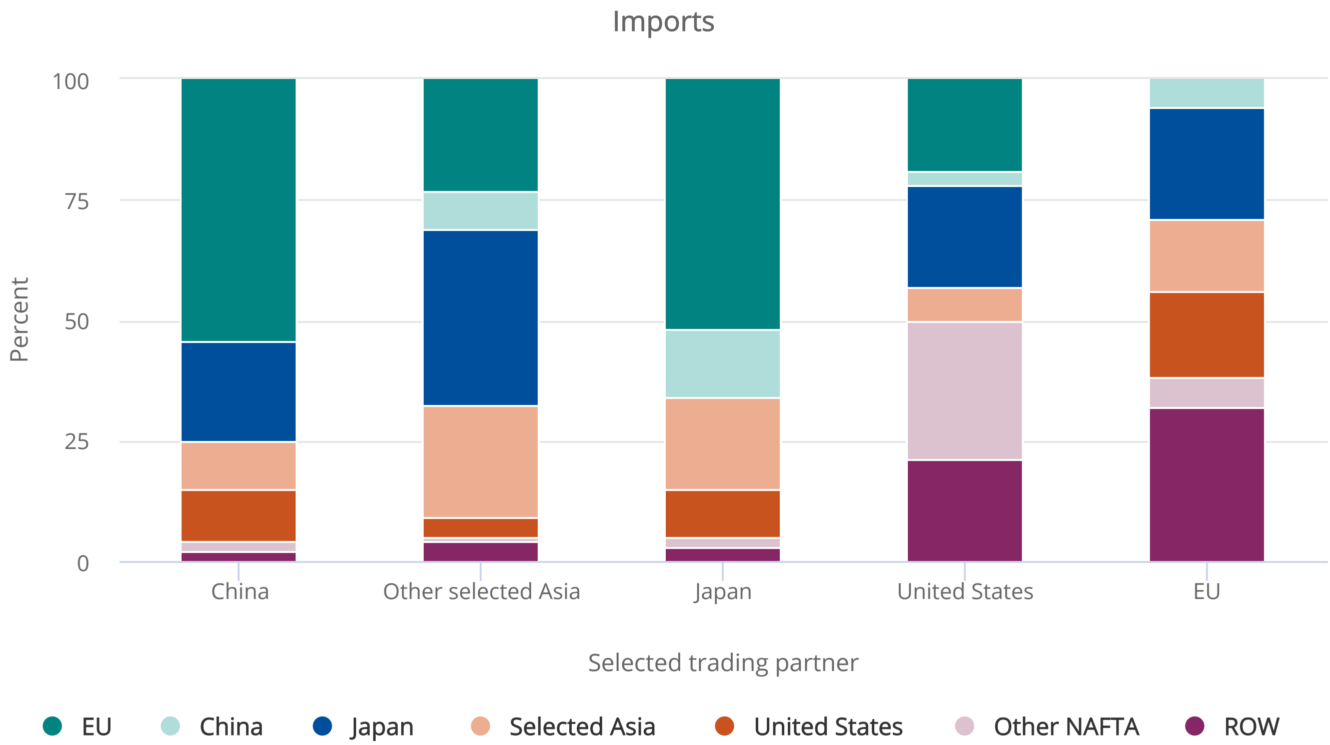
Growth of China's medium-high-technology exports following the global recession has slowed markedly since prior to the recession, from 27% annualized average between 2001 and 2008 to 6% between 2011 and 2016 (Figure 6-29; Appendix Table 6-27). The slowdown of China's medium–high technology exports coincides with the cooling off of growth its high technology exports.

Exports of machinery and equipment drove overall export growth, increasing 40% to reach $218 billion in 2016 (22% global share) (Figure 6-31; Appendix Table 6-41). The trade surplus grew from $21 billion to $111 billion. Exports of motor vehicles and parts had the highest growth rate among the medium-high-technology products (52%), albeit rising from a low base to reach $59 billion (Appendix Table 6-39). Although most cars and trucks manufactured in China are sold for the rapidly growing domestic market, China's industry is also exporting an increasing number of cars and trucks.[11] Major markets for China's exports of motor vehicles and parts are the United States (18% of total exports), other selected Asian economies (12%), and the EU (10%) (Figure 6-32). Exports of electrical equipment and appliances grew by 28% to reach $196 billion (Appendix Table 6-42). China is the dominant global exporter in these products (41% global share). The trade surplus widened from $103 billion to $145 billion.

FIGURE 6-32

Trade in motor vehicles and parts of selected regions, countries, or economies, by selected trading partner: 2016





EU = European Union; NAFTA = North American Free Trade Agreement; ROW = rest of world.

Note(s)

Data are not available for EU members Cyprus, Estonia, Latvia, Lithuania, Luxembourg, Malta, and Slovenia. China includes Hong Kong. EU exports and imports exclude intra-EU trade. China exports and imports exclude trade between China and Hong Kong. The EU excludes Cyprus, Estonia, Latvia, Lithuania, Luxembourg, Malta, and Slovenia. Other selected Asia includes Indonesia, Malaysia, Philippines, Singapore, South Korea, Taiwan, Thailand, and Vietnam.

Source(s)

IHS Global Insight, World Trade Service database (2016). See Appendix Table 6-20.

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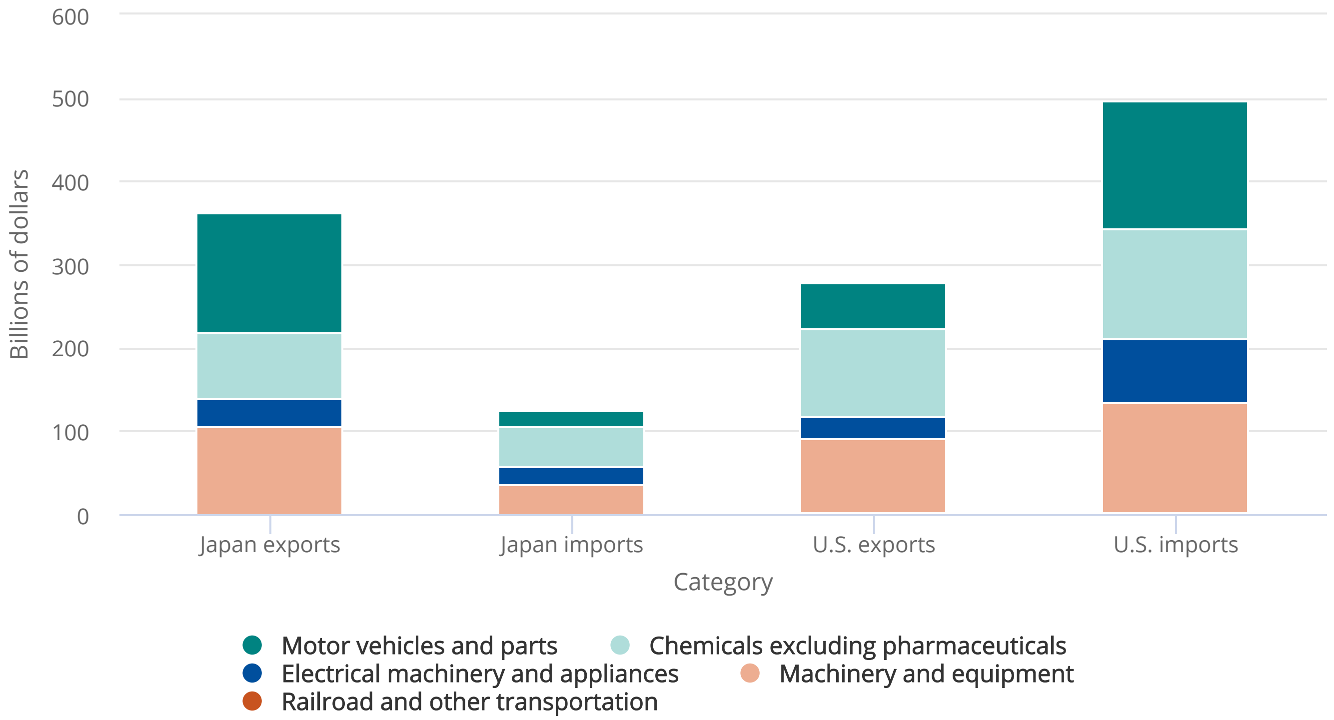
Japan's Trade of Medium-High-Technology Goods

Japan's medium-high-technology exports fell 21% between 2011 and 2016 to reach $364 billion, and its trade surplus declined $80 billion to reach $237 billion (Figure 6-29, Figure 6-30, and Figure 6-33; Appendix Table 6-27).

Exports of chemicals excluding pharmaceuticals, machinery and equipment, and electrical equipment and appliances fell by 25%–27% (Appendix Table 6-40, Appendix Table 6-41, and Appendix Table 6-42). Exports of motor vehicles and parts fell by 11% to reach $144 billion, and the trade surplus declined from $144 billion to $125 billion (Figure 6-33; Appendix Table 6-39). Japan is the second largest exporter of motor vehicles and parts (20% global share). The United States is a major market for Japan's exports of automobiles, trucks, and parts (30% of total exports) (Figure 6-32). The EU (10%) and several Asian countries—Indonesia, Malaysia, Philippines, Singapore, South Korea, Taiwan, Thailand, and Vietnam (13%)—receive a comparatively smaller share of Japan's exports.

FIGURE 6-33

Japan and United States trade in MHT products, by product: 2016



MHT = medium-high technology.

Note(s)

MHT products include motor vehicles and parts, electrical machinery, machinery and equipment, chemicals excluding pharmaceuticals, and railroad and other transportation equipment. Exports and imports of the United States exclude exports to Canada and Mexico.

Source(s)

IHS Global Insight, World Trade Service database (2017). See Appendix Table 6-20.

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U.S. Trade of Medium-High-Technology Goods

U.S. medium-high-technology product exports declined 12% in the post-global recession period of 2011–16 to reach $273 billion (Figure 6-29; Appendix Table 6-27). The U.S. trade deficit nearly doubled from $117 billion to $225 billion during this period (Figure 6-30)[12] Output of U.S. medium-high-technology industries rose by 17% during this period, in contrast to the decline in exports (Figure 6-16 and Figure 6-29; Appendix Table 6-7 and Appendix Table 6-27). The dollar's substantial appreciation against the euro, yen, and other currencies, which made U.S. exports less competitive, may have been a factor in the decline in exports (see sidebar Currency Exchange Rates of Major Economies).

Exports of chemicals excluding pharmaceuticals declined by 15% between 2011 and 2016 to reach $106 billion (Appendix Table 6-40). Exports of machinery and equipment declined by 9% to reach $90 billion (Appendix Table 6-41). Exports of motor vehicles and parts fell slightly from $56 billion to $54 billion (Appendix Table 6-39). The largest major export market is the other NAFTA countries—Canada and Mexico (57%) suggesting that much of the production of inputs, components, and final assembly is located within NAFTA (📊 Figure 6-32).[13] This is because transportation costs are high and companies find it advantageous to co-locate R&D and testing near production so that they can effectively understand and respond to local market conditions.

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[1] Other business services include trade-related services, operational leasing (rentals), and miscellaneous business, professional, and technical services. These include legal, accounting, management consulting, public relations services, advertising, market research and public opinion polling, R&D services, architectural, engineering, and other technical services, agricultural, mining, and on-site processing (WTO 2016:83).

[2] See World Trade Organization, Statistics, Trade in Services (2016).

[3] Other business services include trade-related services, operational leasing (rentals), and miscellaneous business; professional and technical services such as legal, accounting, management consulting, public relations services, advertising, market research, and public opinion polling; R&D services; architectural, engineering, and other technical services; and agricultural, mining, and on-site processing.

[4] A trade surplus occurs when exports exceed imports. A trade deficit occurs when imports exceed exports.

[5] See China Daily (2016) and KPMG (2009) for a discussion of China's outsourcing of business services to other countries.

[6] See IHS Global Insight, World Trade Service database (2016).

[7] The U.S. trade balance is affected by many factors, including currency fluctuations, differing fiscal and monetary policies, and export subsidies and trade restrictions between the United States and its trading partners.

[8] See Green (2014) and Tomiyama (2015) for a discussion on the move of electronics manufacturing from China to Vietnam.

[9] See IHS Global Insight, World Trade Service database (2016).

[10] Intra-EU exports of motor vehicles and parts were $421 billion in 2016. EU exports to the rest of the world were $244 billion. Source: IHS Global Insight, World Trade database.

[11] See https://en.wikipedia.org/wiki/Automotive_industry_in_China.

[12] The U.S. trade balance is affected by many factors, including currency fluctuations, differing fiscal and monetary policies, and export subsidies and trade restrictions between the United States and its trading partners.

[13] U.S. exports of motor vehicles and parts to NAFTA (Canada and Mexico) were $68 billion in 2016. U.S. exports to the rest of the world were $54 billion. Source: IHS Global Insight, World Trade database.

Global Trends in Sustainable Energy Research and Technologies

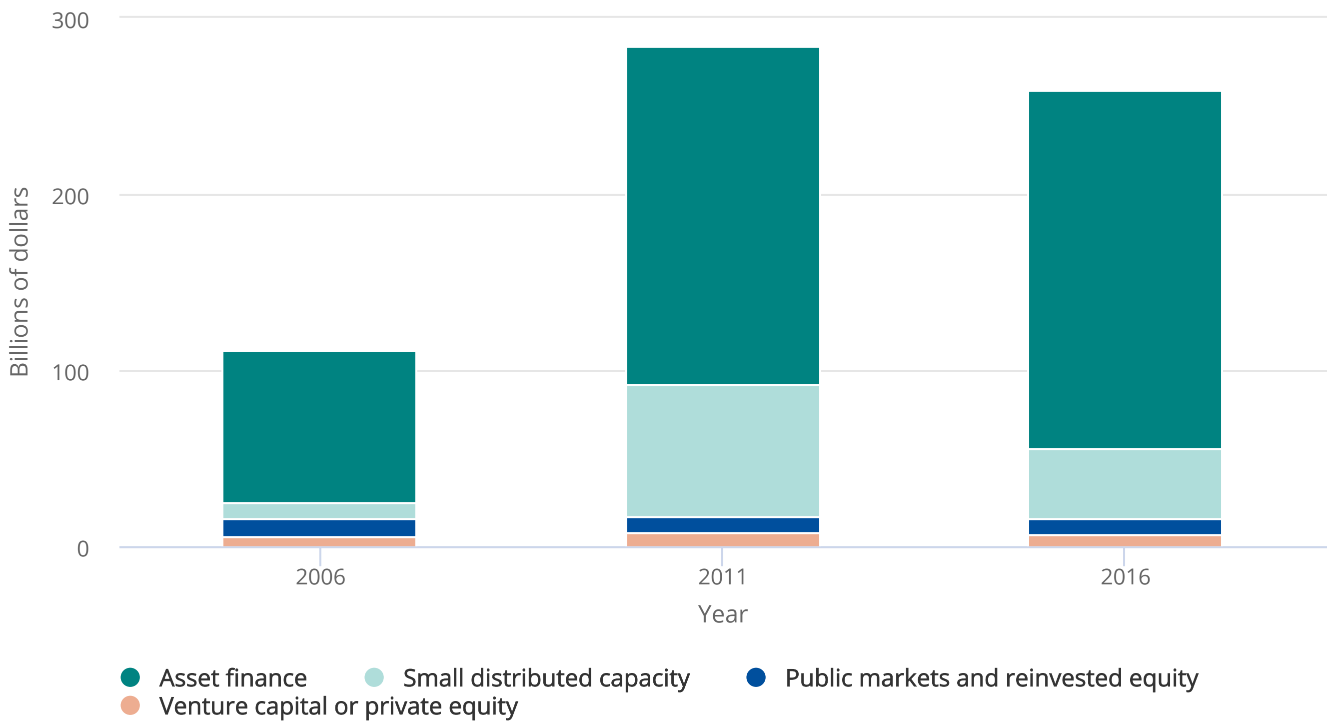
Like KTI industries, sustainable energy has a strong link to scientific R&D and innovation and constitutes a key element of a nation's infrastructure. This section is devoted to examining sustainable energy research and technologies, which include biofuels, solar, wind, energy efficiency, pollution prevention, smart grid, and CO_2 sequestration.

This section examines private investment, public research, development and demonstration (RD&D), and patenting in sustainable energy technologies. We define sustainable energy technologies to include non-fossil fuel energy sources, and technologies that increase energy efficiency or mitigate pollution from fossil fuel sources. Energy from finite sources such as natural gas is not included in the discussion of this section. The coverage of sustainable energy technologies varies among the RD&D, private investment, and patenting used in this section. For example, the public RD&D includes coverage of nuclear energy, which is not covered by the private investment data. In addition, the public RD&D data discussed here are not comparable with the energy R&D data described in Chapter 4.[1]

Private investment consists of early-stage financing—venture capital and private equity—and later stage financing. The data show that, globally, private investment in sustainable energy technologies are significantly larger than public investment (Figure 6-34 and Figure 6-35). Both types of investment have declined in magnitude in recent years due to several factors. Some governments have cut back funding in research on sustainable energy technologies, have curtailed subsidies and incentives to deploy sustainable energy in response to fiscal austerity and sustainable energy technologies becoming economically competitive with fossil fuels in some countries, or both. In addition, the rapidly declining costs of solar photovoltaics have greatly increased the amount of solar energy generated per dollar of investment.

FIGURE 6-34

Private investment in sustainable energy technologies, by type of financing: 2006, 2010, and 2016



Note(s)

Sustainable energy technologies include biomass, geothermal, wind, solar, biofuels, and energy smart and efficiency technologies. Private investment includes asset finance, small distributed capacity, venture capital, private equity, reinvested equity, and public markets. Mergers and acquisitions are excluded.

Source(s)

Bloomberg New Energy Finance, https://about.bnef.com/, accessed 15 May 2017.

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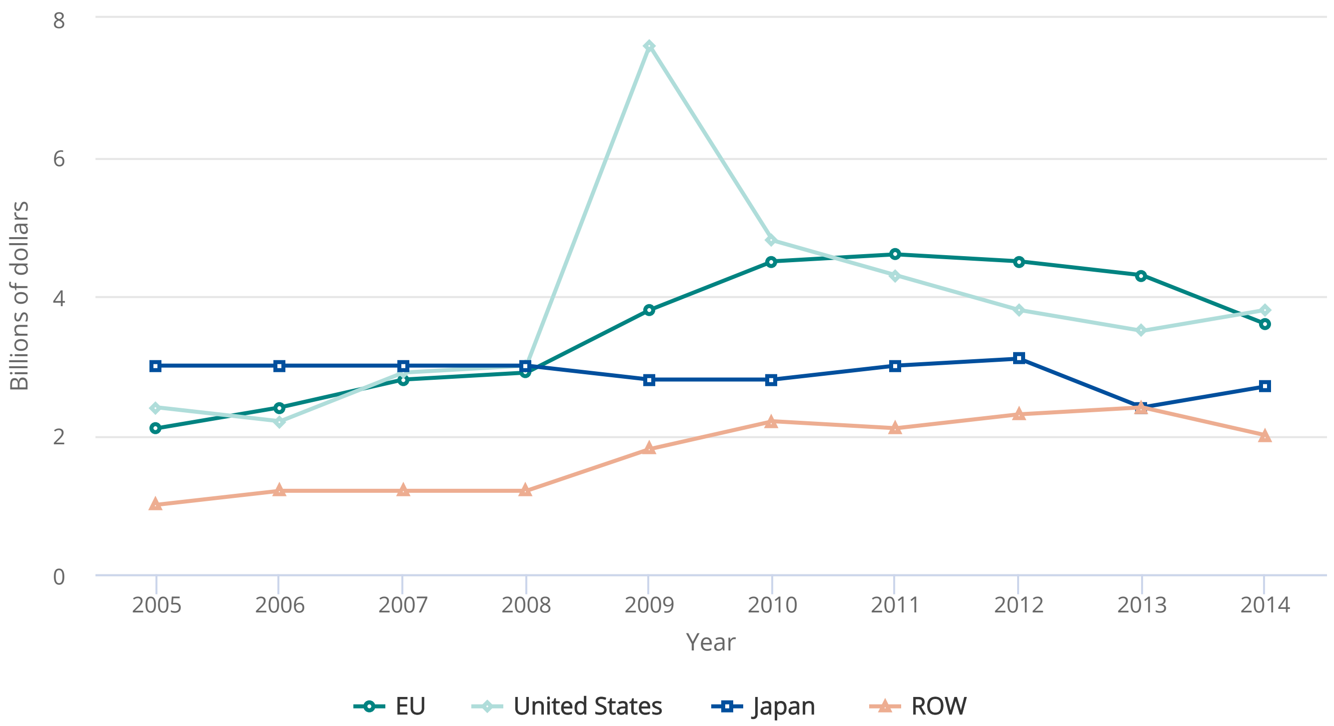
FIGURE 6-35

Government RD&D expenditures on sustainable energy technologies, by selected region, country, or economy: 2005–14



EU = European Union; RD&D = research, development, and demonstration; ROW = rest of world.

Note(s)

Sustainable energy technologies include renewables (solar, wind, biofuels, ocean energy, and hydropower), nuclear, hydrogen and fuel cells, CO_2 capture and storage, other power and storage, and energy efficiency. The EU includes Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Luxembourg, Netherlands, Poland, Portugal, Slovakia, Spain, Sweden, and the United Kingdom. ROW includes New Zealand, South Korea, and Switzerland.

Source(s)

International Energy Agency, Statistics and Balances, https://www.iea.org/statistics/statisticssearch/, accessed 15 February 2017. See Appendix Table 6-54.

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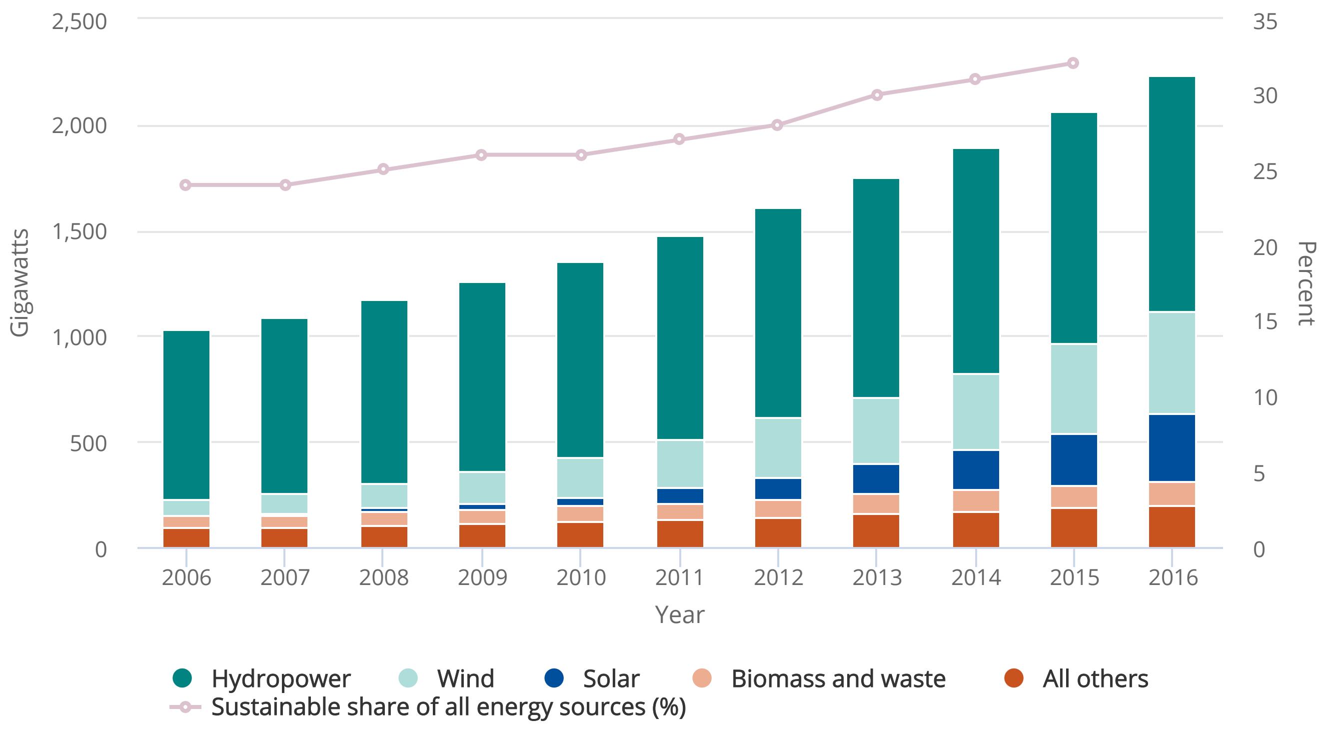
Despite the recent decline of private investment, the sustainable energy share of all energy sources rose from 28% to 32% between 2012 and 2015 (Figure 6-36). The deployment of existing solar and wind projects already under construction and the much cheaper costs of building solar generation capacity drove the increase in the sustainable share during this period.

FIGURE 6-36

Global generation capacity of sustainable energy, by source: 2006–16



Note(s)

Data are not available for all years. Renewable energy includes biomass and waste, geothermal, hydropower, marine, solar, and wind. Renewable share of total is not available for 2016.

Source(s)

Bloomberg New Energy Finance, https://about.bnef.com/, accessed 15 May 2017.

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Private Investment in Sustainable Energy Technologies

Global private investment in sustainable energy technologies, including solar, wind, biofuels, geothermal, and energy smart—was $260 billion in 2016 (Figure 6-34).[2] Private investment consists of early-stage financing—venture capital and private equity ($7.5 billion)—and later stage financing ($252.1 billion)—asset finance (capital based on future expected income streams), public markets, reinvested equity, and small distributed capacity (Appendix Table 6-44).[3] Global private investment is far larger than government RD&D invested in these technologies (government RD&D was estimated at $12 billion in 2014).

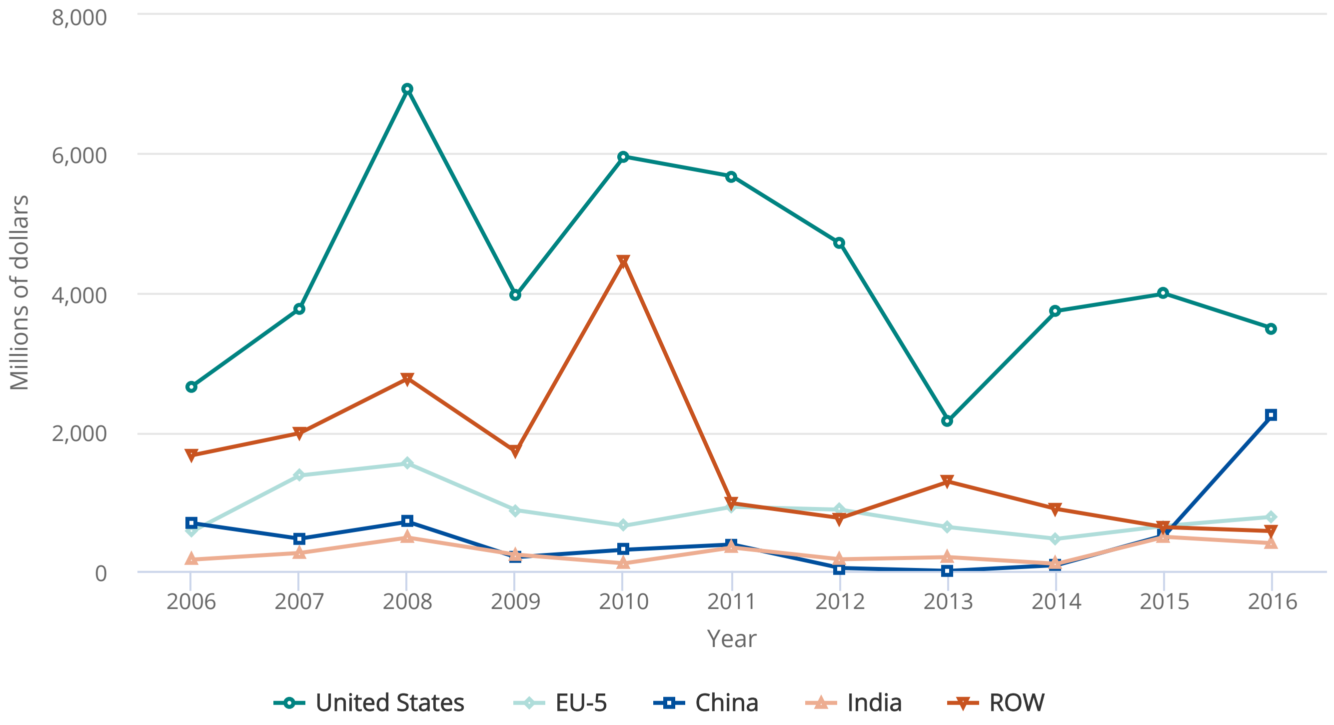
Early-Stage Private Financing of Sustainable Energy Technologies

Venture capital and private equity primarily finance nascent technologies and are important for understanding emerging technology trends. Global venture capital and private equity investment in sustainable energy technologies was $7.5 billion in

2016 (Figure 6-37). The United States attracted the most venture capital and private equity of any country ($3.5 billion in 2016). China attracted $2.2 billion, a record high and huge jump from the $0.5 billion investment in 2015. The five largest economies in the EU—France, Germany, Italy, Spain, and the United Kingdom—attracted a combined $0.8 billion. India attracted $0.4 billion. Energy smart ($4.2 billion) and solar ($2.3 billion) are the leading technologies for venture and capital and private equity investment with biofuels and wind receiving far smaller amounts (Figure 6-37 and Figure 6-38).

FIGURE 6-37

Global venture capital and private equity investment in sustainable energy technologies, by selected region or country: 2006–16



EU = European Union; ROW = rest of world.

Note(s)

EU-5 consists of France, Germany, Italy, Spain, and the United Kingdom. Sustainable energy technologies include wind, solar, biofuels, biomass, geothermal, and energy smart and efficiency technologies.

Source(s)

Bloomberg New Energy Finance, https://about.bnef.com/, accessed 15 February 2017.

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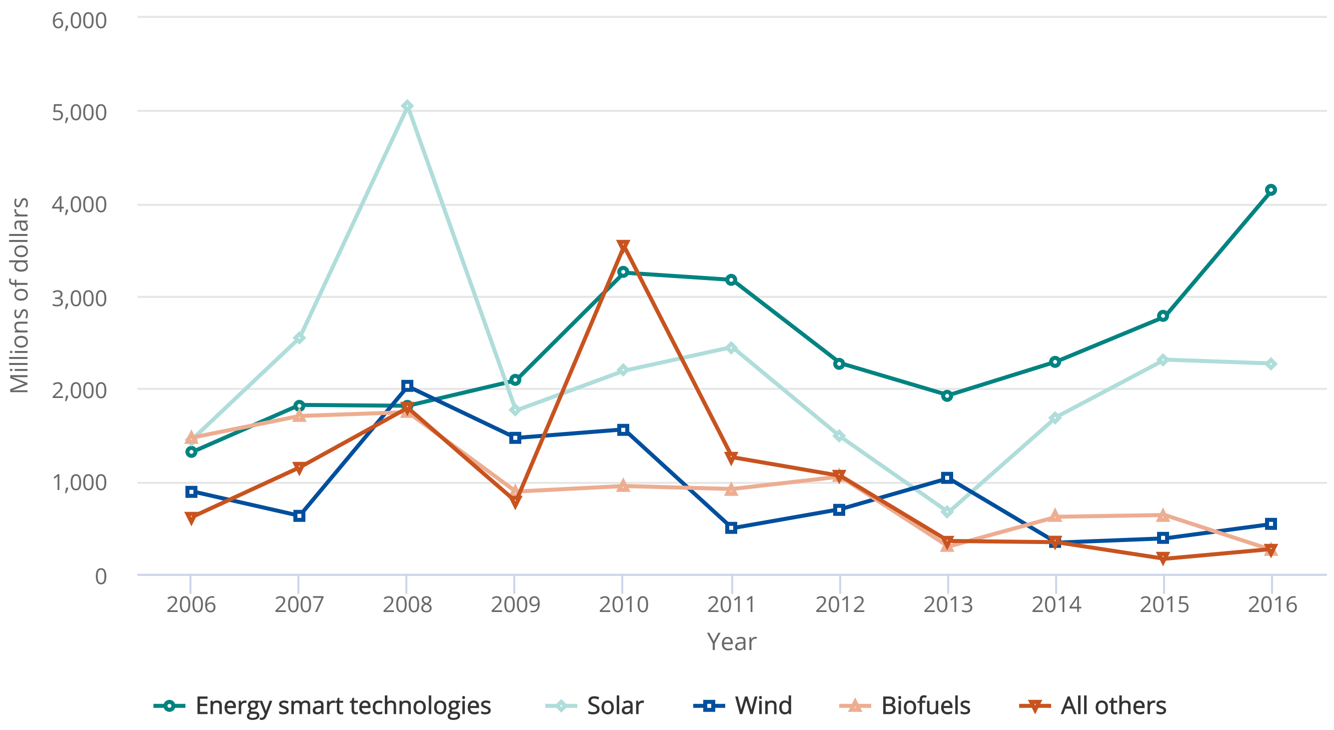
FIGURE 6-38

Global venture capital and private equity investment in sustainable energy technologies, by selected technology: 2006–16



Note(s)

Sustainable energy technologies include wind, solar, biofuels, biomass, geothermal, and energy smart and efficiency technologies.

Source(s)

Bloomberg New Energy Finance, https://about.bnef.com/, accessed 15 February 2017.

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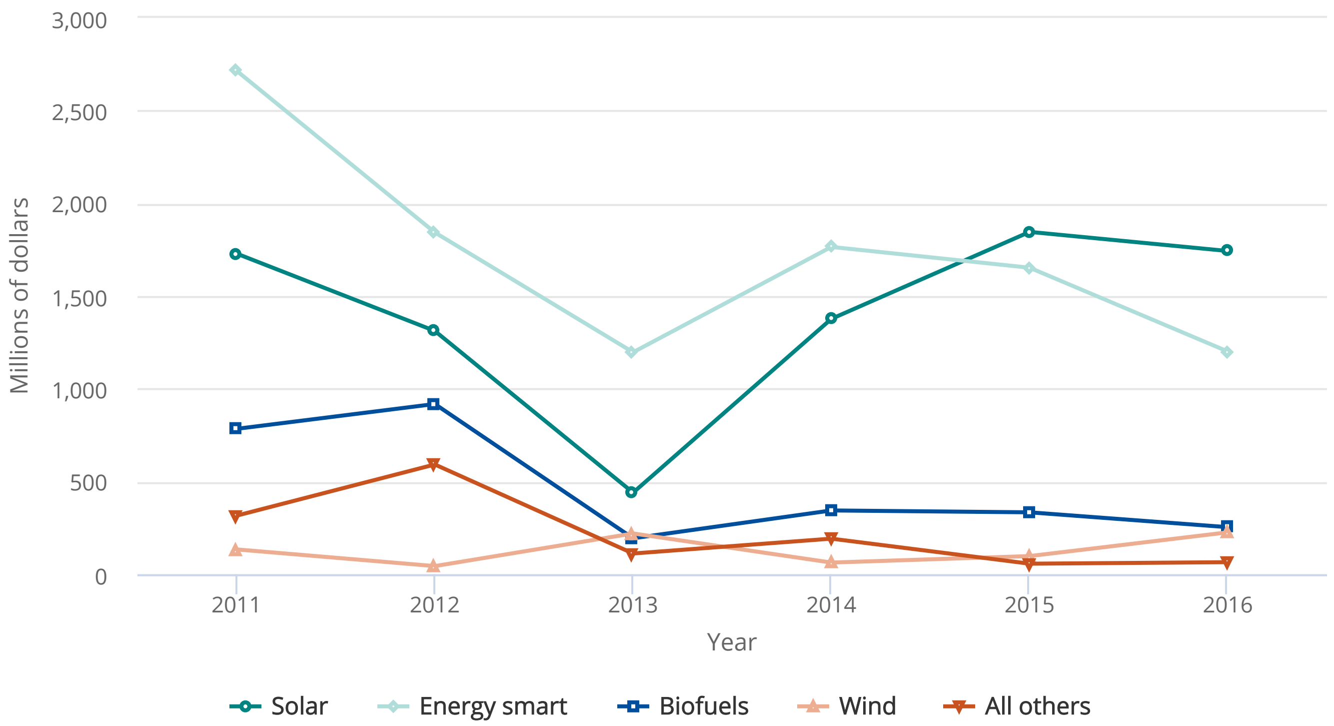
Although venture capital and private equity investment grew from $4.3 billion in 2013 to $7.5 billion in 2016, it remains far below its peak in 2008 ($12.4 billion) (Figure 6-37). The sharp decline in investment starting in 2011 has been attributed to the difficulty of venture capitalists raising new funds and the lack of getting a sufficient positive return on their existing investments in sustainable energy technology companies. Commercializing energy technologies such as solar, wind, and biofuels can be very risky and sometimes requires subsequent substantial and long-term financing to build demonstration plants. Investors in venture capital have become more risk adverse and expect returns within the relatively short time horizon of 2–4 years.

U.S. venture capital and private equity investment has paralleled the trend of global venture capital and private equity investment over the post-global recession period (Figure 6-39). The largest two technology areas have been energy smart and solar between 2011 and 2015. Both areas saw declining investments following the global recession but have recovered in recent years.

FIGURE 6-39

U.S. venture capital and private equity investment in sustainable energy technologies, by selected technology: 2011–16



Note(s)

Sustainable energy technologies include biomass, geothermal, wind, solar, biofuels, and energy smart and efficiency technologies.

Source(s)

Bloomberg New Energy Finance, https://about.bnef.com/, accessed 15 February 2017.

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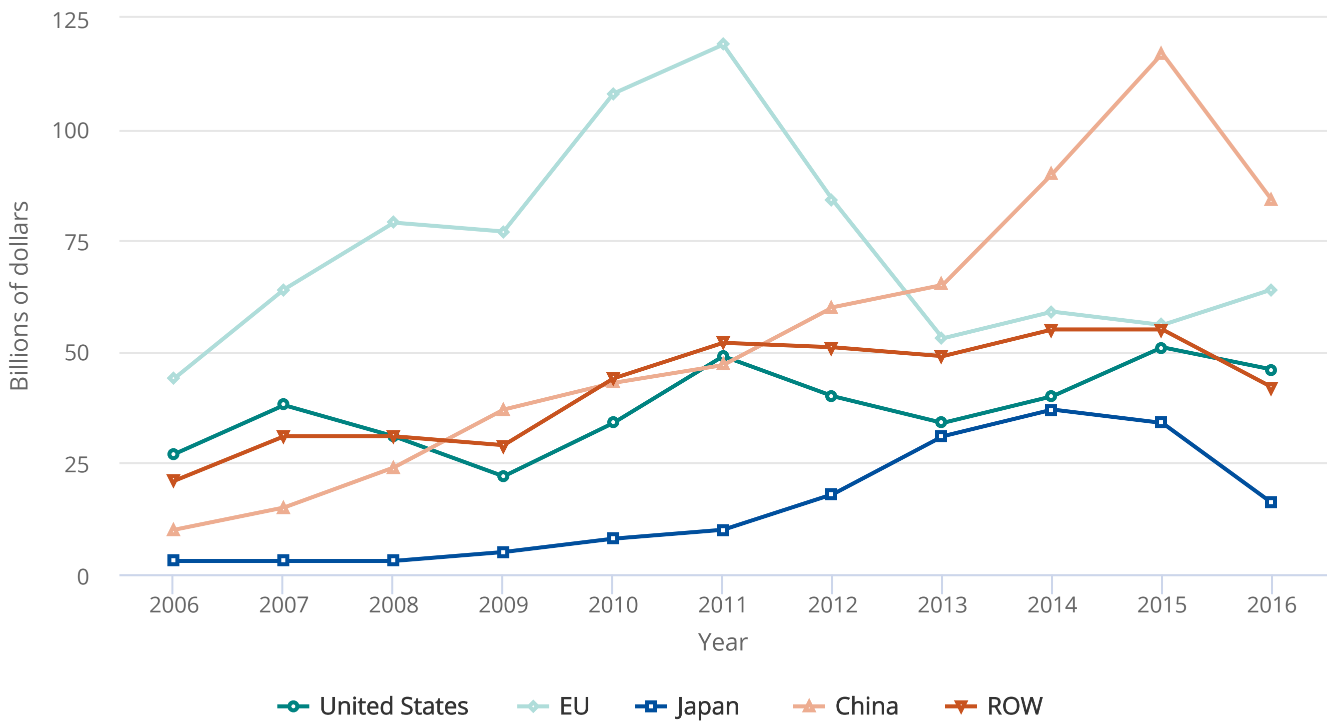
Later-Stage Private Investment in Sustainable Energy Technologies

Later-stage financing is focused on the design and construction of utility-scale renewable energy power plants and installations (primarily solar) on commercial and residential buildings. Global later-stage private investment in sustainable energy technologies was $252 billion in 2016 (Figure 6-40 and Figure 6-41).[4] Two technologies—wind and solar—dominate sustainable energy technology investment, each with a share of about 40% (Appendix Table 6-44 and Appendix Table 6-45). Energy smart technologies are the third largest area (8%). China leads the world in attracting later-stage private investment in sustainable energy technologies (with a global share of 33%) followed by the EU (25%) and the United States (18%) (Figure 6-40).

FIGURE 6-40

Later-stage private investment in sustainable energy technologies, by selected region or country: 2006–16



EU = European Union; ROW = rest of world.

Note(s)

Data for 2016 are preliminary. Sustainable energy technologies include biomass, geothermal, wind, solar, biofuels, and energy smart and efficiency technologies. Later-stage private investment includes asset financing, small scale distributed capacity, mergers and acquisitions, public equity, and reinvested equity.

Source(s)

Bloomberg New Energy Finance (2017), https://about.bnef.com/, accessed 15 February 2017.

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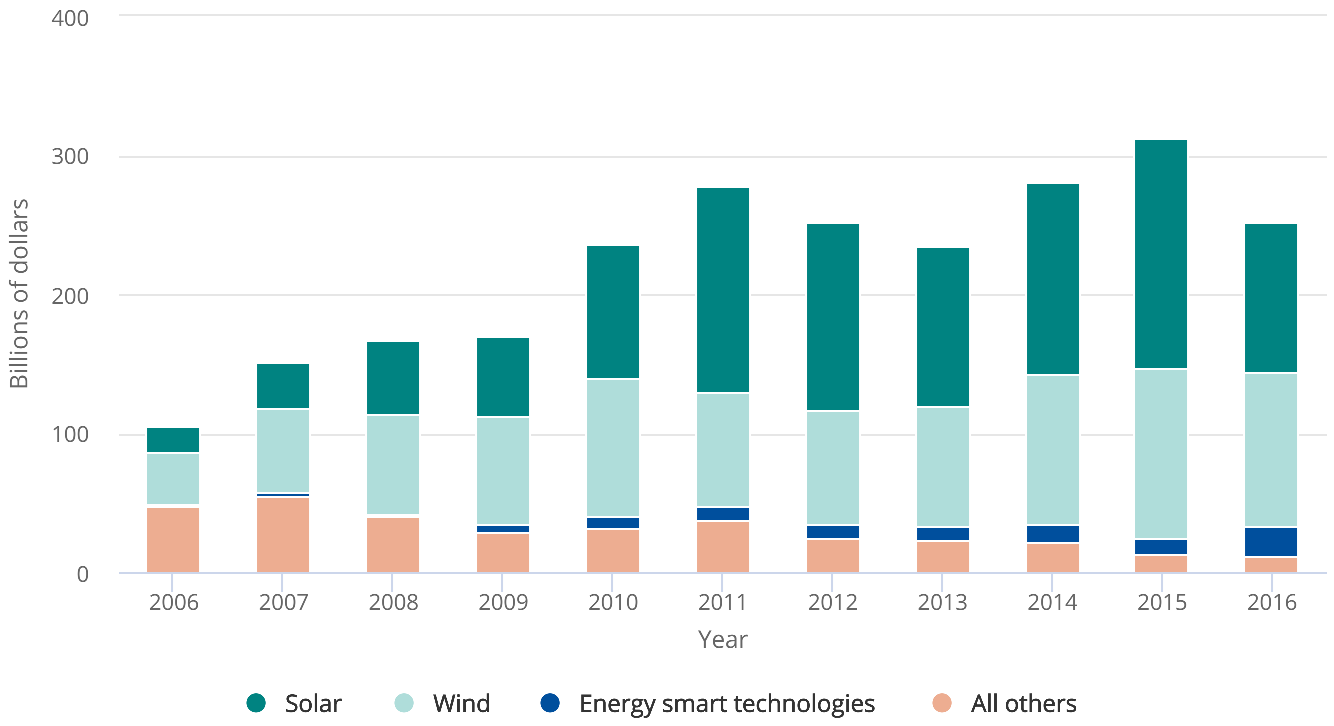
Global later-stage investment in sustainable energy technologies fell 19% to $252 billion in 2016 compared to 2015, the deepest annual decline over the last decade (Figure 6-40 and Figure 6-41; Appendix Table 6-44). Solar had the deepest decline (35%) among technologies, falling from a record high in 2015 to $108 billion in 2016, and wind declined 10% to reach $111 billion (Appendix Table 6-45). Investment declined steeply in China (29%) and in Japan (51%) with a far more modest decline in the United States (8%). Investment in the EU increased by 14%. Both China and Japan have shifted some of their focus from building up energy capacity to efficiently managing and integrating existing energy capacity into electric grids (BNEF 2017).

Global sustainable energy technology investment following the global recession has fluctuated compared to the very rapid growth prior to the recession (Figure 6-40 and Figure 6-41; Appendix Table 6-45). The plateauing of global investment following the global recession has been due to several factors including the sluggish global economy, cutbacks by many governments on incentives to deploy sustainable energy, and rapid declines in costs of solar photovoltaics, which in turn have reduced the per-unit cost of investment in these technologies. As a result of these lower costs, solar generation capacity can grow despite lower current dollar expenditures.

FIGURE 6-41

Later-stage private investment in sustainable energy technologies, by selected technology: 2006–16



Note(s)

Sustainable energy technologies include biomass, geothermal, wind, solar, biofuels, and energy smart and efficiency technologies. Later-stage private investment includes asset financing, small scale distributed capacity, mergers and acquisitions, public equity, and reinvested equity.

Source(s)

Bloomberg New Energy Finance, https://about.bnef.com/, accessed 15 February 2017.

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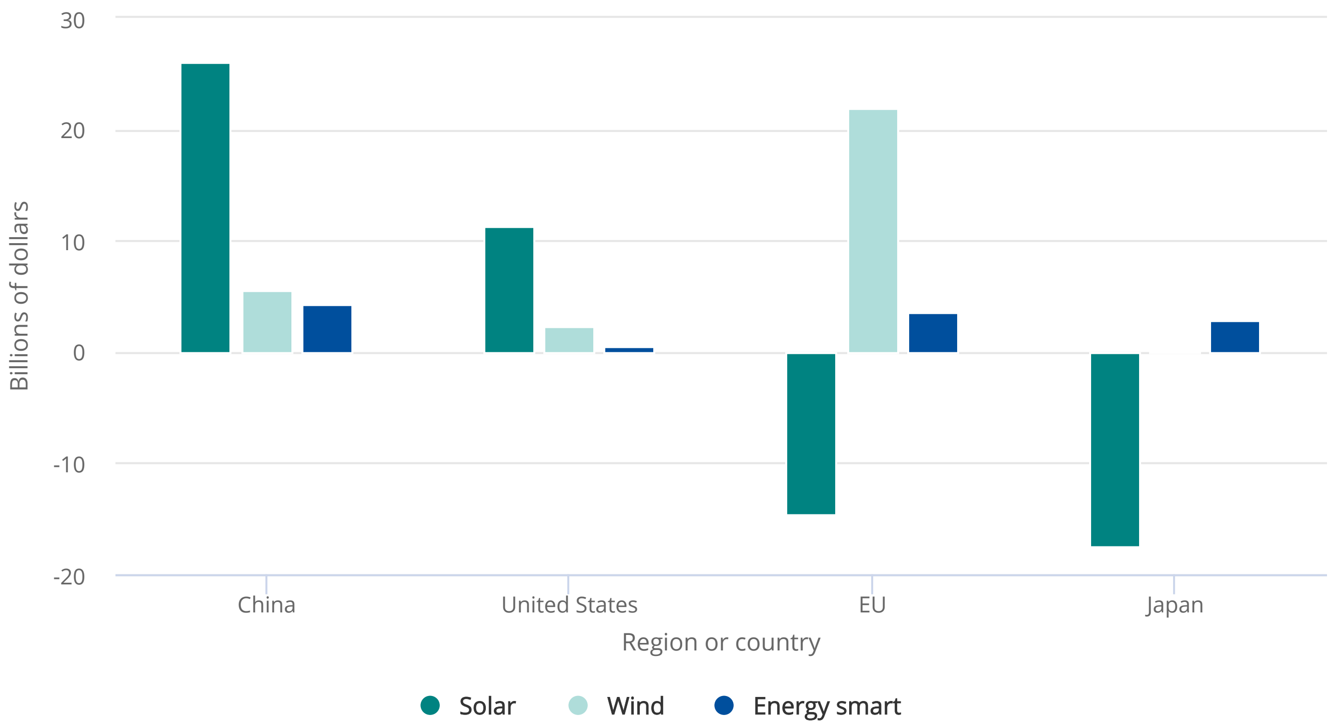
Later-Stage Sustainable Energy Investment in China

Later-stage investment in China fell 29% in 2016 to $84 billion following 13 years of uninterrupted growth (Figure 6-40; Appendix Table 6-44). The sharp decline of investment in 2016 reflects the government paring back its incentives for building solar and wind energy capacity and focusing on investing in its electric grids and reforming the power market to efficiently utilize its existing wind and energy capacity.[5] In addition, the plunging cost of solar photovoltaics has sharply raised the amount of solar energy capacity produced per dollar of investment. The rapid growth of sustainable energy technology investment between 2002 and 2015 has been driven by the government's policies and generous incentives targeted at wind and solar energy to make China a major world producer and build up its energy capacity in these technologies. Between 2013 and 2016, investment in solar drove China's growth in later stage sustainable energy technology investment (Figure 6-42; Appendix Table 6-44). Solar investment climbed from $27 billion to $39 billion, making China the leading country in solar investment. China's rapid rise reflects its emergence as a major manufacturer of low-cost photovoltaic modules and rapidly growing installation of utility scale and residential solar in China. China had modest growth in investment in wind energy (from $26 billion in 2011 to $35 billion in 2016) (Appendix Table 6-45).

FIGURE 6-42

Cumulative change in later-stage sustainable energy technologies private investment, by selected region or country and technology area: 2013–16



EU = European Union.

Note(s)

Sustainable energy technologies include biomass, geothermal, wind, solar, biofuels, and energy smart and efficiency technologies. Later-stage private investment includes asset financing, small scale distributed capacity, mergers and acquisitions, public equity, and reinvested equity

Source(s)

Bloomberg New Energy Finance, https://about.bnef.com/, accessed 15 February 2017.

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Later-Stage Sustainable Energy Investment in the EU

EU investment in 2016 rose 14% to reach $64 billion (Figure 6-40; Appendix Table 6-44). Between 2013 and 2016, investment in the EU rose from $53 billion to $64 billion, driven by a $22 billion increase in wind investment driven by several large wind offshore installations (BNEF 2017) (Figure 6-42; Appendix Table 6-45). The EU surpassed China during this period to become the world's largest recipient of wind investment. Solar investment declined by $15 billion during this period. The big drop in EU investment between 2011 and 2013 reflects a mix of factors including retroactive cuts in support for existing solar projects in Spain and other countries, cutbacks in incentives to deploy solar and wind energy, the economic downturn in Spain and southern European countries, the slowdown in solar investment in Germany and Italy, and the big fall in the cost of solar photovoltaics (Appendix Table 6-44).

Later-Stage Sustainable Energy Investment in the United States

U.S. sustainable energy technology investment fell 8% (from $51 billion to $46 billion) in 2016 (Figure 6-40; Appendix Table 6-44). Investment in the United States has fluctuated between $34 billion and $51 billion in the post-global recession period. The changing status of two key federal government tax incentives, the Production Tax Credit (PTC) for wind and the Investment Tax Credit (ITC) for solar, has been a key factor in the fluctuation of U.S. investment over the last several years.[6] Solar investment has been the main component of U.S. investment between 2013 and 2016 due to deep declines in the cost of photovoltaics, which have increased solar generation per unit of investment, and the adoption of leasing and other innovative financing methods that have lowered the cost of residential solar installation (Figure 6-42; Appendix Table 6-44).[7]

Later-Stage Sustainable Energy Investment in Japan

Investment in Japan fell by half in 2016 to reach $16 billion following rapid growth between 2011 and 2014 (Figure 6-40; Appendix Table 6-45). The sharp drop in solar investment drove the steep decline in Japan's sustainable energy technology investment (Figure 6-42). Japan, like China, is cutting back on building large-scale solar installations and shifting toward managing and integrating their existing solar energy capacity into its electric grid (BNEF 2017). Sustainable energy investment in Japan soared between 2011 and 2015 largely because of generous government incentives for solar investment enacted in response to the government's push to diversify energy sources in the wake of the Fukushima nuclear reactor accident in 2011.

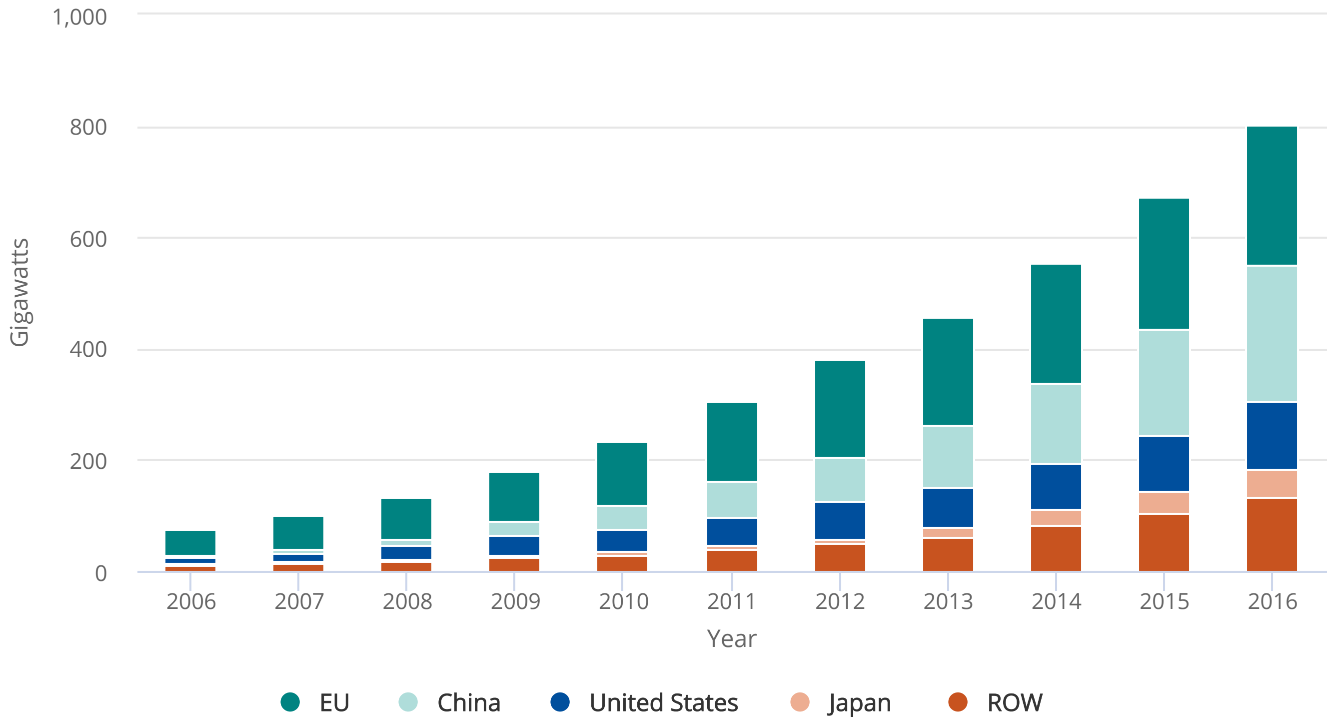
Sustainable Energy Generation Capacity

The large expansion of investment and deployment of sustainable energy technologies over the last decade has led to rapid growth in renewable energy generation capacity (Figure 6-36). Renewable energy capacity excluding hydropower jumped from 130 gigawatts in 2006 to 912 gigawatts in 2016.[8] Despite the decline in sustainable energy technology investment, the world added a record 137 gigawatts of renewable energy capacity excluding hydropower in 2016. Solar and wind have driven the surge in renewable energy capacity, accounting for more than 90% of the increase in capacity of all renewable energy sources except hydropower over the last decade. Solar and wind generation capacity added a record amount of 130 gigawatts in 2016 (Figure 6-43). Although global sustainable energy technology investment has plateaued following the global recession, sustainable energy capacity has continued to increase because the deployment of solar and wind projects already under construction and the rapidly falling costs of solar photovoltaics that have greatly increased the amount of solar energy generated per investment dollar.[9]

China has led the world in increasing solar and wind generation capacity. Between 2010 and 2016, China added a cumulative 200 gigawatts of solar and wind generation capacity with China nearly reaching the capacity of the EU (Figure 6-43). Despite the sharp fall in sustainable energy technology investment, the EU added a cumulative 137 gigawatts in capacity. The United States (82 gigawatts) added far less than China and the EU.

FIGURE 6-43

Generation capacity in solar and wind by selected region or country: 2006–16



EU = European Union; ROW = rest of world.

Source(s)

Bloomberg New Energy Finance, https://about.bnef.com/, accessed 15 February 2017.

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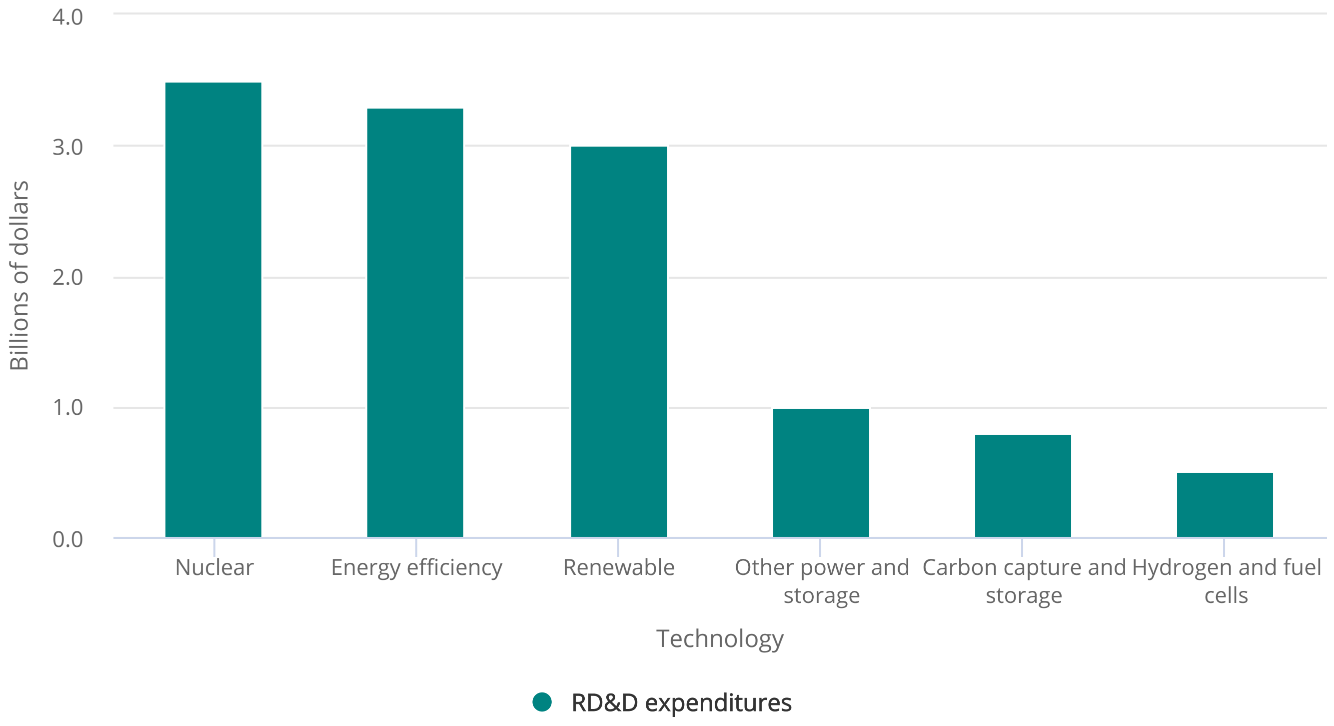
Public RD&D Expenditures in Sustainable Energy Technologies

Global public investment in RD&D in sustainable energy technologies—renewables, energy efficiency, capture and storage of CO_2, nuclear, fuel cells, and other power and storage technologies—was an estimated $12.0 billion in 2014 (Figure 6-35 and Figure 6-44; Appendix Table 6-46 through Appendix Table 6-55).[10] Nuclear was the largest area ($3.5 billion), followed by energy efficiency ($3.3 billion) and renewables ($3.0 billion). These technologies typically require costly investment to construct testing and demonstration plants that businesses are unwilling to finance and thus require substantial public funding.

FIGURE 6-44

Government RD&D expenditures on sustainable energy technologies, by technology: 2014



RD&D = research, development, and demonstration.

Note(s)

Sustainable energy technologies include renewables (solar, wind, biofuels, ocean energy, and hydropower), nuclear, hydrogen and fuel cells, CO_2 capture and storage, other power and storage, and energy efficiency.

Source(s)

International Energy Agency, Statistics and Balances, https://www.iea.org/statistics/statisticssearch/, accessed 15 November 2016. See Appendix Table 6-54.

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Global public RD&D has steadily declined following the global recession after spiking at $16.2 billion in 2009 because of stimulus spending by the United States under the American Recovery and Reinvestment Act of 2009 (Figure 6-35; Appendix Table 6-46). Between 2011 and 2014, global public RD&D declined from $14 billion to $12 billion (Appendix Table 6-46 through Appendix Table 6-55). Nuclear declined by 19% to reach $3.5 billion. Renewables fell 23% to reach $3.0 billion with a steep decline in solar (39%). CO_2 capture and storage declined by nearly a third to reach $0.8 billion. Energy efficiency increased slightly (10%) to reach $3.3 billion.

The United States surpassed the EU in 2014 to become the world's largest investor in public RD&D despite the 12% decline in U.S. investment between 2011 and 2014 (Figure 6-35; Appendix Table 6-46). The fall in U.S. public RD&D investment between 2011 and 2014 resulted from steep declines in renewables (26%) and nuclear energy (32%) (Appendix Table 6-47 and

Appendix Table 6-50). In renewables, solar funding plunged 71% to $0.1 billion (Appendix Table 6-51). Expenditures on biofuels rose 41% to reach $0.5 billion (Appendix Table 6-53). Funding for energy efficiency technologies rose 40% to reach $1.3 billion (Appendix Table 6-48).

EU investment in RD&D fell 22% between 2011 and 2014 to reach $3.6 billion with declines across all technology areas (Figure 6-35; Appendix Table 6-46 through Appendix Table 6-54. The EU's cutbacks in RD&D funding, particularly in renewable energy coincide with fiscal austerity in many EU countries and the sharp declines in subsidies and other incentives to deploy solar and wind generation.

Japan's RD&D fell 10% between 2011 and 2014 to reach $2.7 billion (Figure 6-35; Appendix Table 6-46). Nuclear energy fell 17% to reach $1.4 billion and was far below its level in 2009 (Appendix Table 6-47). Japan's government has cut funding to nuclear RD&D in the wake of the Fukushima accident in 2011 and has diversified its energy sources, including increasing its generation of solar energy.

Patenting of Sustainable Energy Technologies

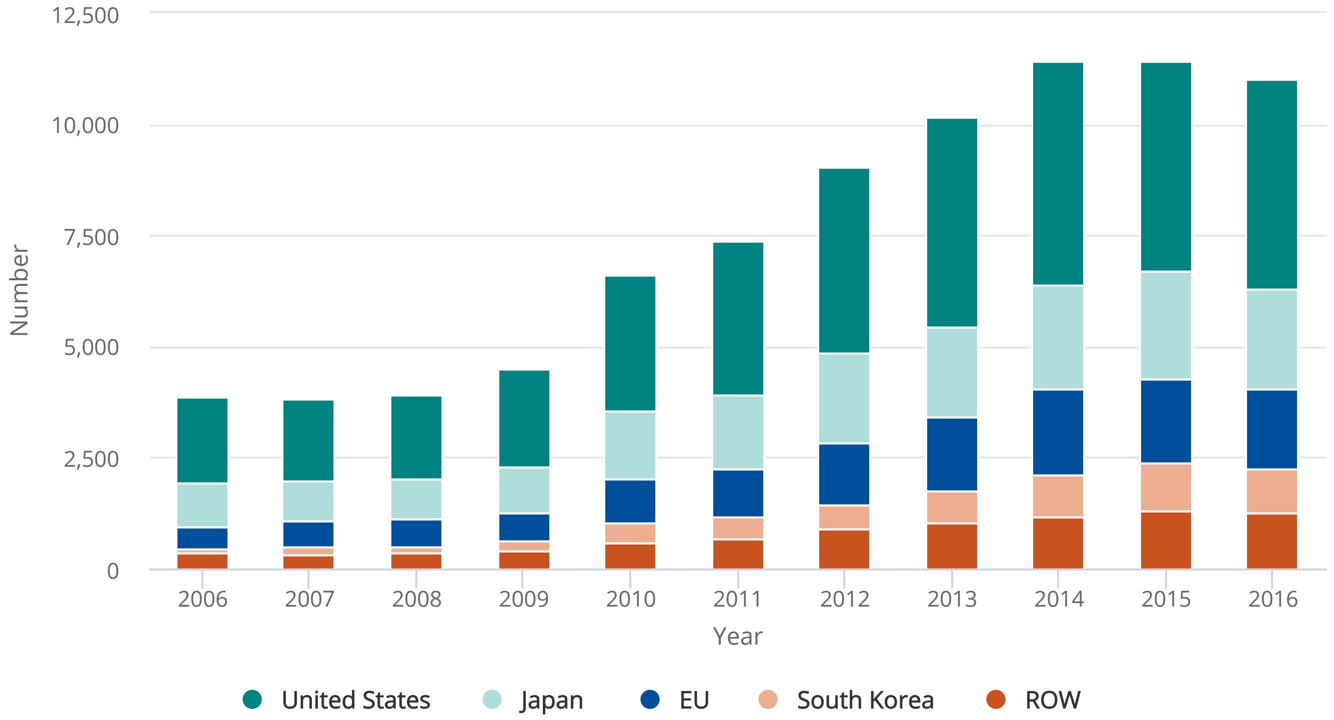
Patents are a partial indicator of invention and are used as a measure of the invention capacity of countries or to help identify nascent technologies that could be commercialized. In some technologies, including energy, venture-backed firms obtain patent protection for technologies they intend to commercialize. This section uses patent activity at the U.S. Patent and Trademark Office (USPTO). It is one of the largest patent offices in the world and has a significant share of applications from and grants to foreign inventors because of the size and openness of the U.S. market. (See Chapter 8 for a discussion of the limitations of using patents as an indicator of inventiveness and information on USPTO patents.)

Sustainable energy technology patents comprise four broad areas: alternative energy, energy storage, smart grid, and pollution mitigation (Appendix Table 6-56 through Appendix Table 6-60). These broad categories are further divided into finer technology areas (Appendix Table 6-61 through Appendix Table 6-74). (For more information on this classification of sustainable energy patent technologies, which was developed by the National Science Foundation [NSF], please see *Identifying Clean Energy Supply and Pollution Control Patents.*[11])

U.S. resident inventors were granted 43% of all sustainable energy technology patents in 2016 (Figure 6-45; Appendix Table 6-56). The next four largest recipient economies were Japan (20%), the EU (16%), and South Korea (9%). Although the global leader in attracting sustainable energy technology investment, China accounts for a relatively small share (3%) of USPTO sustainable energy technology patents (Figure 6-46).

FIGURE 6-45

USPTO patents in sustainable energy technologies, by selected region, country, or economy of inventor: 2006–16



EU = European Union; ROW = rest of world; USPTO = U.S. Patent and Trademark Office.

Note(s)

Sustainable energy technologies include alternative energy, energy storage, smart grid, and pollution mitigation. Alternative energy includes solar; wind; nuclear; fuel cell; hydropower; wave, tidal, ocean; geothermal; and electric or hybrid. Energy storage includes batteries, compressed air, flywheels, superconductivity, magnet energy systems, ultracapacitors, hydrogen production and storage, and thermal energy. Pollution mitigation includes recycling; control of air, water, and solid waste pollution; environmental remediation; cleaner coal; and capture and storage of carbon and other greenhouse gases. Technologies are classified by The Patent Board. Patent grants are fractionally allocated among regions or countries on the basis of the proportion of the residences of all named inventors.

Source(s)

Science-Metrix, PatentsView, and USPTO patent data. See Appendix Table 6-57.

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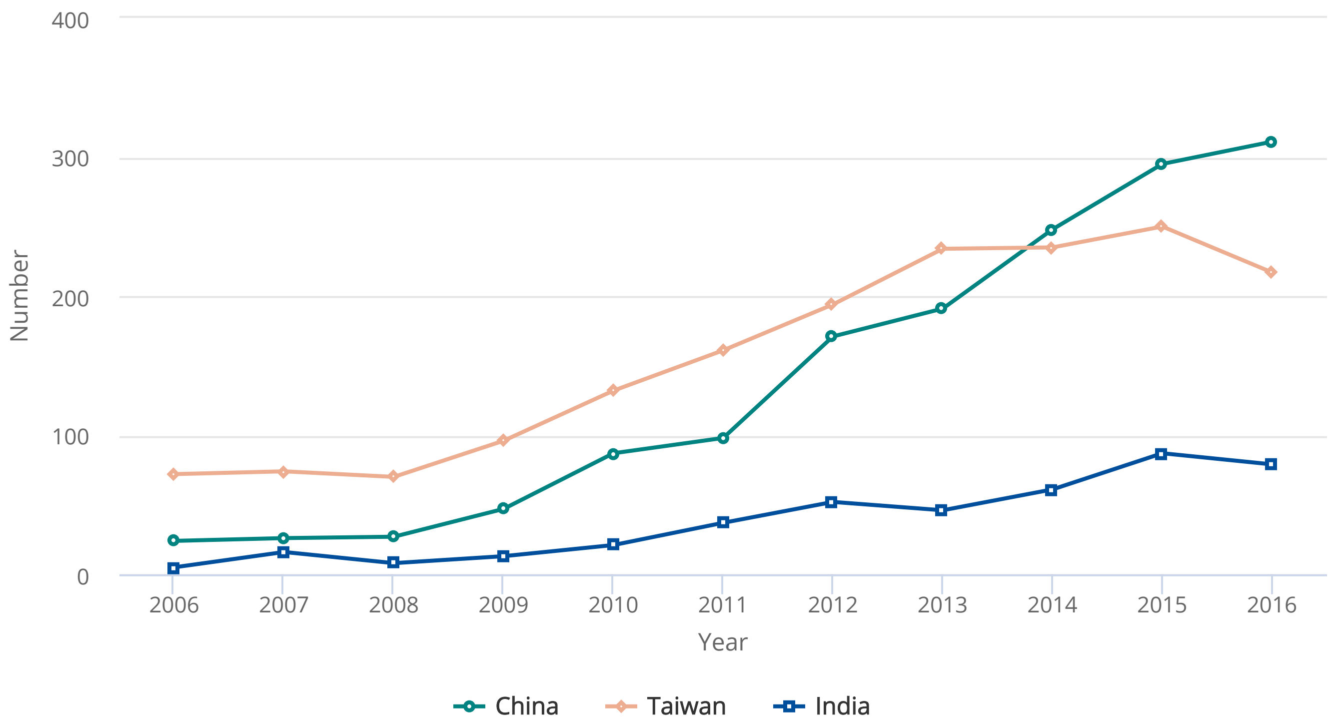
FIGURE 6-46

USPTO patents in sustainable energy technologies, by selected region, country, or economy of inventor: 2006–16



USPTO = U.S. Patent and Trademark Office.

Note(s)

Sustainable energy technologies include alternative energy, energy storage, smart grid, and pollution mitigation. Alternative energy includes solar; wind; nuclear; fuel cell; hydropower; wave, tidal, ocean; geothermal; and electric or hybrid. Energy storage includes batteries, compressed air, flywheels, superconductivity, magnet energy systems, ultracapacitors, hydrogen production and storage, and thermal energy. Pollution mitigation includes recycling; control of air, water, and solid waste pollution; environmental remediation; cleaner coal; and capture and storage of carbon and other greenhouse gases. Technologies are classified by The Patent Board. Patent grants are fractionally allocated among regions or countries on the basis of the proportion of the residences of all named inventors.

Source(s)

Science Metrix; PatentsView and USPTO patent data. See Appendix Table 6-57.

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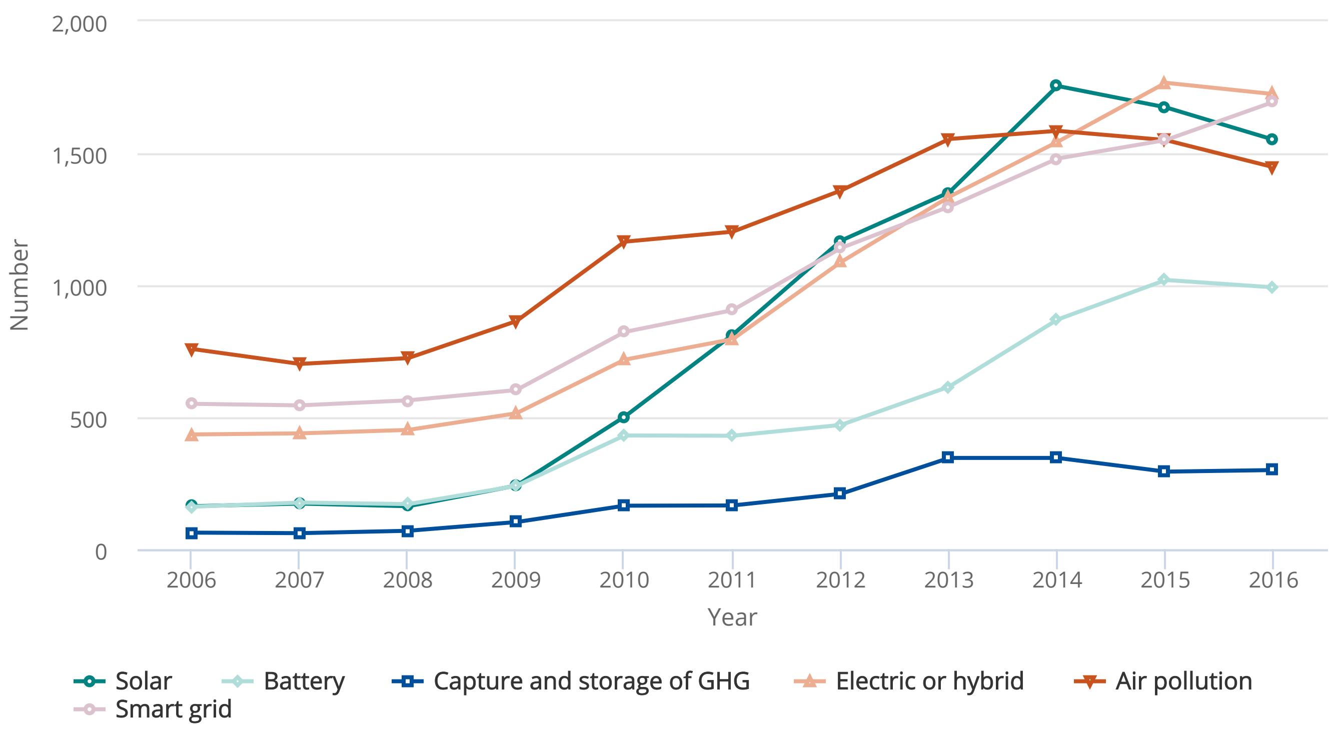
The number of patents in these technologies has risen in line with the rapid growth of all USPTO patents since 2009 (Figure 6-45; Appendix Table 6-56).[12] Six technologies—solar, hybrid and electric vehicles, smart grid, fuel cell, battery, capture and storage of carbon and other greenhouse gases—led the growth of sustainable energy technology patents between 2009 and 2016 (Figure 6-47; Appendix Table 6-59, Appendix Table 6-61, Appendix Table 6-63, Appendix Table 6-64, Appendix Table 6-67, and Appendix Table 6-70).

FIGURE 6-47

USPTO patents in sustainable energy technologies, by selected technology: 2006–16



GHG = greenhouse gas; USPTO = U.S. Patent and Trademark Office.

Note(s)

Sustainable energy technologies include alternative energy, energy storage, smart grid, and pollution mitigation. Alternative energy includes solar; wind; nuclear; fuel cell; hydropower; wave, tidal, ocean; geothermal; and electric or hybrid. Energy storage includes batteries, compressed air, flywheels, superconductivity, magnet energy systems, ultracapacitors, hydrogen production and storage, and thermal energy. Pollution mitigation includes recycling; control of air, water, and solid waste pollution; environmental remediation; cleaner coal; and capture and storage of carbon and other GHGs. Technologies are classified by The Patent Board. Patent grants are fractionally allocated among regions or countries on the basis of the proportion of the residences of all named inventors.

Source(s)

Science-Metrix, PatentsView, and USPTO patent data. See Appendix Table 6-57.

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U.S. sustainable energy technology patents more than doubled between 2009 and 2016 to reach 4,700 patents led by growth in four technology areas—hybrid and electric vehicles, solar, smart grid, and energy storage (Figure 6-45; Appendix Table 6-56, Appendix Table 6-58, Appendix Table 6-59, Appendix Table 6-63, and Appendix Table 6-64).

Patents granted to inventors outside the United States, primarily in Asia, grew faster than those granted to the United States, resulting in U.S. global share declining from 49% in 2009 to 43% in 2016. Japan's patents more than doubled to reach 2,200, led by growth in solar, hybrid electric, and battery (Figure 6-45; Appendix Table 6-56, Appendix Table 6-63, Appendix Table 6-64, and Appendix Table 6-67). The number of EU patents tripled, resulting in the EU's share edging up from 14% to 16% (Figure 6-45; Appendix Table 6-56). Four technologies—solar, hybrid electric, smart grid, and wind—drove overall growth (Appendix Table 6-59, Appendix Table 6-63, Appendix Table 6-64, and Appendix Table 6-65).

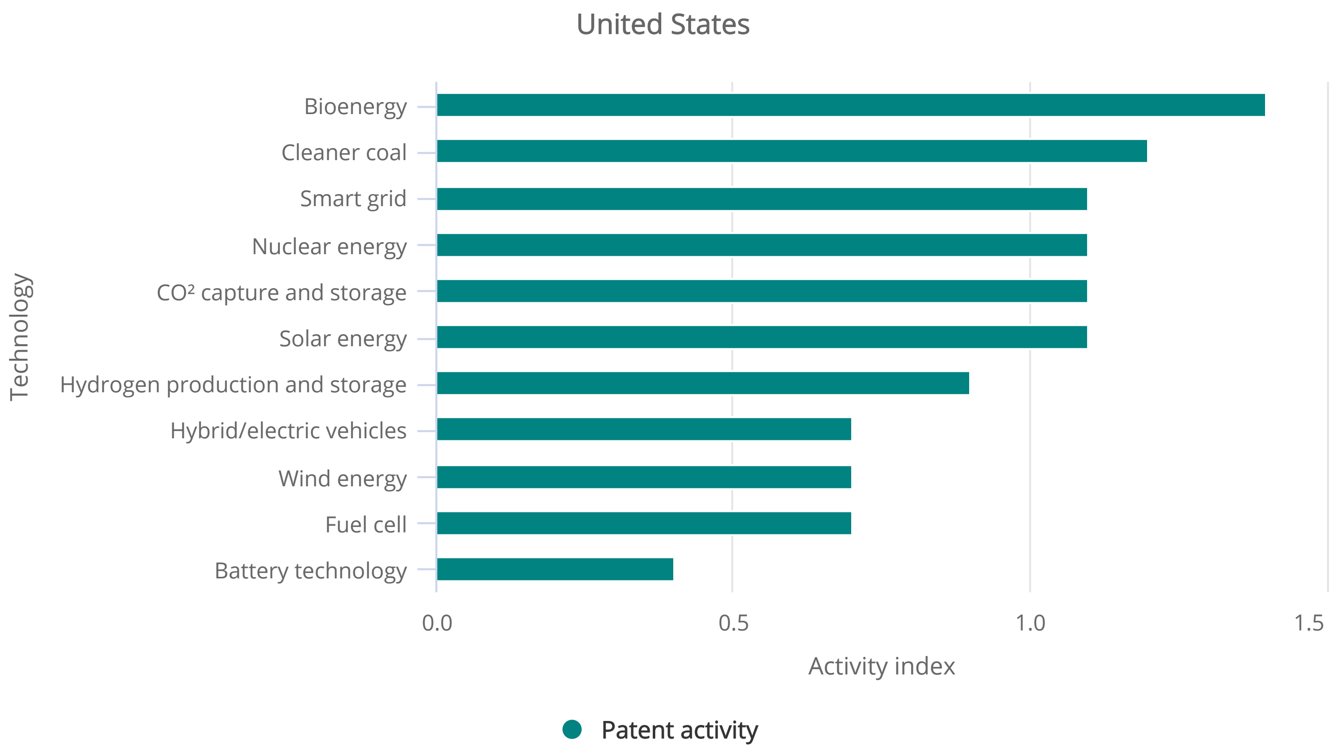
South Korea's patents more than quadrupled to reach 1,000 resulting in its global share nearly doubling to reach 9% (Figure 6-45). Growth was very rapid in energy storage, solar, hybrid/electric, and battery technologies (Appendix Table 6-58, Appendix Table 6-63, Appendix Table 6-64, and Appendix Table 6-67). Patents granted to China and Taiwan have increased rapidly, though from a very low base (Figure 6-46; Appendix Table 6-56).

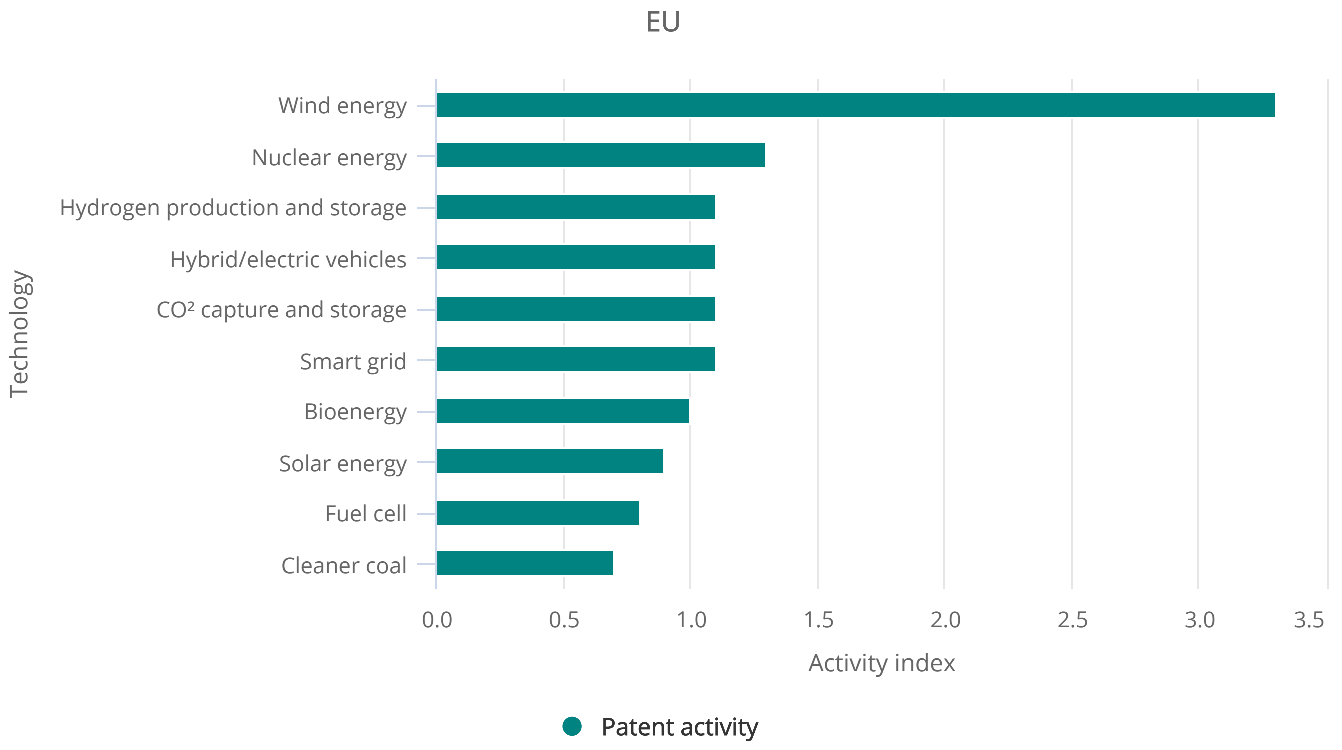
The patenting technology activity index indicates the extent to which a country specializes in that area. This indicator is indexed to 1.00, which represents the world level, meaning that a score above 1.00 shows that a country produces more of its patent output in the given technological area than the global proportion, whereas a score below 1.00 shows that a country produces fewer patents in this technological area than the global proportion. Technologies with an activity index of 1.2 or more are defined here as relatively more concentrated. (See Chapter 8 for a discussion on the limitations of using the patenting technology activity index.)

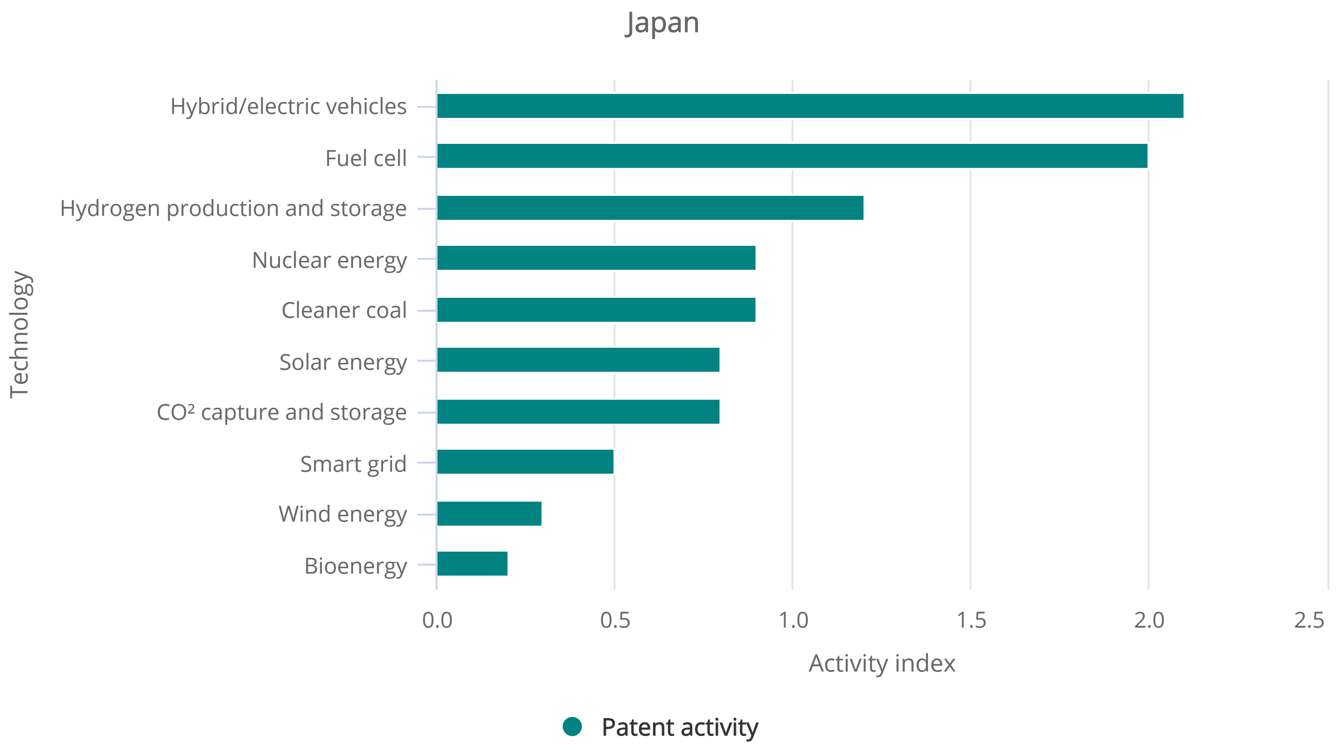
The United States has a relatively high concentration of patenting in bioenergy and cleaner coal (Figure 6-48; Appendix Table 6-62 and Appendix Table 6-69). The EU has a relatively high concentration in wind and nuclear energy (Figure 6-48; Appendix Table 6-65 and Appendix Table 6-66). Japan has a relatively high concentration in hybrid and electric vehicles, fuel cells, and hydrogen production and storage (Figure 6-48; Appendix Table 6-61, Appendix Table 6-64, and Appendix Table 6-68). South Korea has an extremely high concentration in batteries (6.3) and fuel cells (2.4) and a relatively high concentration in solar, hybrid and electric vehicles, and nuclear energy (Figure 6-48; Appendix Table 6-61, Appendix Table 6-63, Appendix Table 6-64, Appendix Table 6-66, and Appendix Table 6-67).

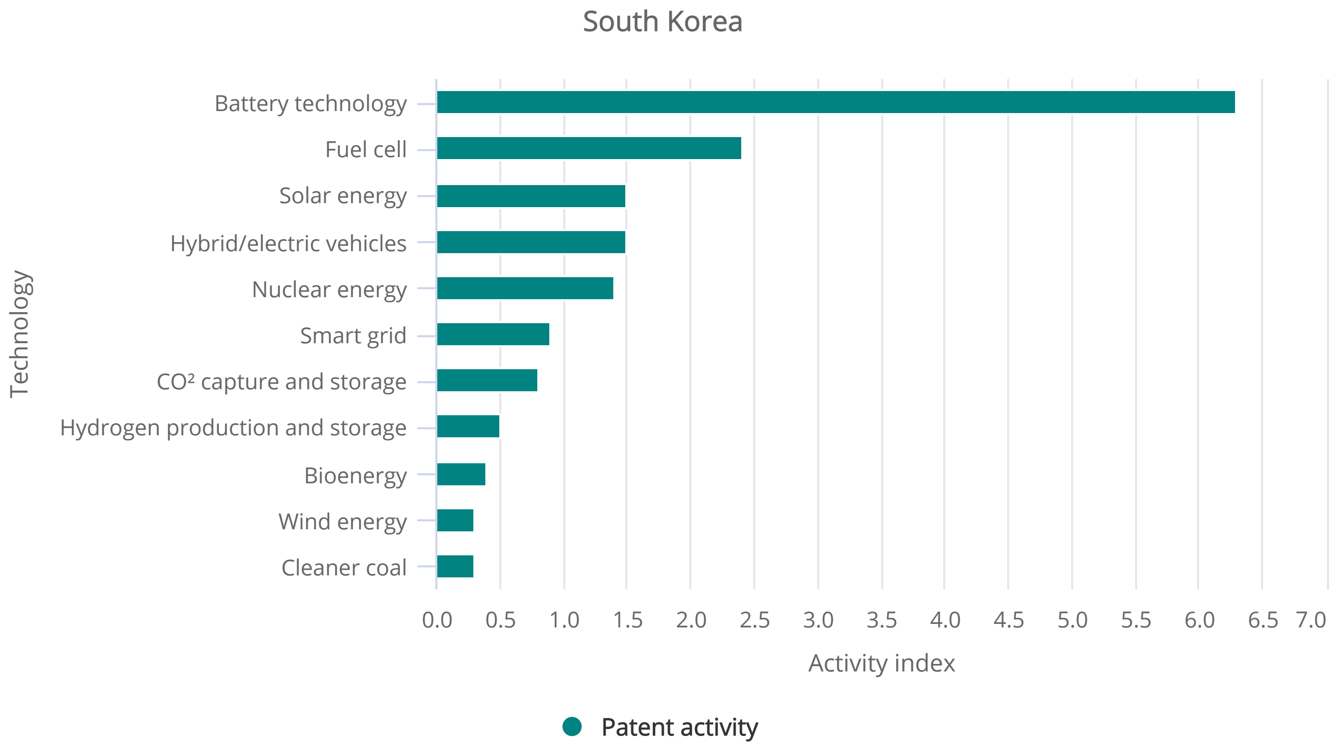
FIGURE 6-48

Patent activity index of selected sustainable energy technologies for the United States, the EU, Japan, and South Korea: 2014–16




EU
Technology
Wind energy
Nuclear energy
Hydrogen production and storage
Hybrid/electric vehicles
CO² capture and storage
Smart grid
Bioenergy
Solar energy
Fuel cell
Cleaner coal
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Activity index
● Patent activity


Japan
Technology
Hybrid/electric vehicles
Fuel cell
Hydrogen production and storage
Nuclear energy
Cleaner coal
Solar energy
CO² capture and storage
Smart grid
Wind energy
Bioenergy
0.0
0.5
1.0
1.5
2.0
2.5
Activity index
● Patent activity



EU = European Union.

Note(s)

A patent activity index is the ratio of a country's share of a technology area to its share of all patents. A patent activity index greater (less) than 1.0 indicates that the country is relatively more (less) active in the technology area. Patents are allocated according to patent inventorship information. Patents are fractionally allocated among regions, countries, or economies based on the proportion of residences of all named inventors. The EU includes 28 member countries. Technologies are based on a classification developed by The Patent Board. Data were extracted in April 2017.

Source(s)

Science-Metrix, PatentsView, and USPTO patent data.

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[1] The International Energy Agency (IEA) manual states: "The IEA concept of Energy RD&D differs from the Frascati concept of R&D, in that (i) it focuses on energy related programmes only; (ii) it includes 'demonstration projects'; and (iii) it includes state owned companies.... The energy RD&D data collected by the IEA should not be confused with the data on government budget appropriations or outlays on R&D (GBAORD) collected by the OECD Directorate for Science, Technology, and Industry for the socio-economic objective 'Production, distribution and rational utilisation of energy'" (IEA 2011:16–17).

[2] Energy smart covers a wide range of technologies, from digital energy applications to efficient lighting, electric vehicles, and the smart grid that maximize the energy efficiency of existing energy sources and networks.

[3] Small distributed capacity consists largely of installation of solar photovoltaics on commercial and residential structures

[4] Bloomberg's data include investment in renewable energy, biofuels, energy efficiency, smart grid and other energy technologies, CO_2 capture and storage, and infrastructure investments targeted purely at integrating clean energy. Investment in solar hot water, combined heat and power, renewable heat, and nuclear are excluded, as are the proceeds of mergers and acquisitions (which do not contribute to new investment).

[5] BNEF (2017). In the first half of 2016, 21% of wind power in China went to waste and 12% of solar power in northern China was curtailed according to the World Resources Institute. See http://www.wri.org/blog/2017/01/china-leaving-us-behind-clean-energy-investment.

[6] The PTC and ITC lapsed at the end of 2013, and were reinstated briefly in December 2014. After being unavailable for most of 2015, Congress extended the PTC and ITC for a full 5 years.

[7] "Third party" financing has become a popular method of financing residential solar installation in the United States that is less expensive than purchasing a residential solar system. Under this type of financing, a customer can sign a traditional lease and pay for the use of a solar system or a customer can sign a power purchase agreement to pay a specific rate for the electricity that is generated each month. For more information, see http://www.seia.org/policy/finance-tax/third-party-financing.

[8] One gigawatt is a unit of electric power equal to one billion watts.

[9] BNEF, https://about.bnef.com/clean-energy-investment/. Accessed 28 February 2017.

[10] This discussion includes public research, development, and demonstration in energy efficiency, renewable energy, nuclear, hydrogen and fuel cells, CO_2 capture and storage, and other power and storage technologies.

[11] See D'Amato, Hamilton, and Hill (2015) for more information on NSF's classification of clean energy patents.

[12] The USPTO initiated a green technology pilot program on 7 December 2009 that expedites processing of some applications related to green technologies. For more information, see http://www.uspto.gov/patents/init_events/green_tech.jsp.

Conclusion

The global science and technology landscape is changing rapidly. Knowledge-intensive production and trade account for increasing shares of global output and are closely related to country and regional investment in S&E education and in R&D activity (Chapter 2 and Chapter 4 provide information on S&E higher education and R&D activity). While the United States and the EU continue to be leading global producers in many knowledge-intensive industries, the production and assembly of many high-technology goods have shifted to the developing world, particularly in China, where ICT and pharmaceutical manufacturing have become large shares of global production. Exports of high-technology products are centered in Asia, where China accounts for 24% of global exports, but smaller nations such as Vietnam are expanding rapidly. Although this production activity often represents the final phase of the global supply chain, where components designed or produced in other countries are transformed into final products, there is increasing evidence that China is moving from final assembly into higher-value activities, including R&D and manufacture of sophisticated products. Overall, the United States is the largest producer of high-technology manufacturing output with China being the largest global producer in the ICT manufacturing industries. China is by far the world's largest global producer in medium-high-technology industries. In commercial knowledge-intensive services (such as banking, finance insurance, R&D services), the United States and the EU lead in the volume of output while China is growing rapidly and now the third largest producer.

China is the world's largest global exporter in high-technology manufactured products and the second largest in medium-high-technology products. China has substantial trade surpluses in most of these products. However, conventional trade statistics likely exaggerate China's position because China's exports contain substantial content supplied by other countries, including the United States. China's exports of commercial knowledge-intensive services are growing rapidly and are in surplus.

The United States continues to have a strong competitive position in some technology-based industries. The United States remains the global leader in commercial knowledge-intensive services, which include many sophisticated industries such as R&D and civil engineering. The commercial knowledge-intensive industries account for nearly a fifth of global economic activity. The United States is the global leader in the high-technology manufacturing industries of aerospace and scientific measuring and control instruments. U.S. KTI industries have grown robustly compared to weak or negative growth of the EU and Japan following the global recession. Despite the strong recovery of U.S. KTI output, gains in employment have been limited and confined to commercial knowledge-intensive services.

The United States has a weaker position than other major economies in trade of technology-intensive goods. The United States is the world's third and fourth largest exporter of high-technology and medium-high-technology goods, respectively, and has substantial trade deficits in most of these goods. In high-technology goods, the United States remains the world's largest exporter of aerospace products and has a substantial surplus. However, conventional trade statistics likely overstate the weakness of the United States because U.S. exports of sophisticated intermediate goods to China and other countries are not included in the value of U.S. exports.

In sustainable energy research and technology, the United States is the global leader in attracting early-stage investment and is the largest investor in public RD&D in these technologies. Large-scale public investment in RD&D is important because many sustainable energy research and technology require costly large-scale testing and demonstration plants that are too risky for the private sector to finance entirely. The EU and Japan are major investors in public RD&D. China is the leading recipient of commercial-scale private investment and is leading the world in increasing its renewable energy capacity. In addition, China is the world's largest solar manufacturer and is a major wind manufacturer.

Glossary

Definitions

Commercial knowledge-intensive (KI) services: Knowledge-intensive services that are generally privately owned and compete in the marketplace without public support. These services are business, information, and financial services.

Company or firm: A business entity that is either in a single location with no subsidiaries or branches or the topmost parent of a group of subsidiaries or branches.

European Union (EU): The EU comprises 28 member nations: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, and the United Kingdom. Unless otherwise noted, data on the EU include all 28 nations.

Foreign direct investment: Financial investment by which a person or an entity acquires a lasting interest in and a degree of influence over the management of a business enterprise in a foreign country.

Gross domestic product (GDP): The market value of all final goods and services produced within a country within a given period of time.

High-technology manufacturing industries: Industries formerly classified by the OECD that spend a high proportion of their revenue on R&D. These industries consist of aerospace; pharmaceuticals; computers and office machinery; semiconductors and communications equipment; and measuring, medical, navigation, optical, and testing instruments.

Information and communications technologies (ICT) industries: A subset of knowledge- and technology-intensive industries, consisting of two high-technology manufacturing industries, computers and office machinery and communications equipment and semiconductors, and two knowledge-intensive services industries, information and computer services, which is a subset of business services.

Intellectual property: Intangible property resulting from creativity that is protected in the form of patents, copyrights, trademarks, and trade secrets.

Intra-EU exports: Exports from European Union (EU) countries to other EU countries.

Knowledge- and technology-intensive (KTI) industries: Those industries that have a particularly strong link to science and technology. These industries are five service industries—financial, business, communications, education, and health care; five high-technology manufacturing industries—aerospace; pharmaceuticals; computers and office machinery; semiconductors and communications equipment; and measuring, medical, navigation, optical, and testing instruments; and five medium-high-technology industries—motor vehicles and parts, chemicals excluding pharmaceuticals, electrical machinery and appliances, machinery and equipment, and railroad and other transportation equipment.

Knowledge-intensive services industries: Those industries that incorporate science, engineering, and technology into their services or the delivery of their services, consisting of business, information, education, financial, and health care.

Medium-high-technology manufacturing industries: Industries formerly classified by the OECD that spend a relatively high proportion of their revenue on R&D. These industries consist of motor vehicles and parts, chemicals excluding pharmaceuticals, electrical machinery and appliances, machinery and equipment, and railroad and other transportation equipment.

Productivity: The efficiency with which resources are employed within an economy or industry, measured as labor or multifactor productivity. Labor productivity is measured by gross domestic product (GDP) or output per unit of labor. Multifactor productivity is measured by GDP or output per combined unit of labor and capital.

Public knowledge-intensive services: An industry category consisting of education and healthcare. These are publicly regulated or provided and remain relatively more location bound than the commercial knowledge-intensive services.

Value added: A measure of industry production that is the amount contributed by a country, firm, or other entity to the value of the good or service. It excludes the country, industry, firm, or other entity's purchases of domestic and imported supplies and inputs from other countries, industries, firms, and other entities.

Value chain: A chain of activities to produce goods and services that may extend across firms or countries. These activities include design, production, marketing and sales, logistics, and maintenance.

Venture capital Venture capitalists manage the pooled investments of others (typically wealthy investors, investment banks, and other financial institutions) in a professionally managed fund. In return, venture capitalists receive ownership equity and almost always participate in managerial decisions.

Key to Acronyms and Abbreviations

EU: European Union

GDP: gross domestic product

GHG: greenhouse gas

HS: Harmonized Commodity Description and Coding System, or Harmonized System

HT: high technology

ICT: information and communications technologies

IEA: International Energy Agency

IMF: International Monetary Fund

IoT: Internet of Things

IT: information technology

ITC: Investment Tax Credit

KI: knowledge intensive

KTI: knowledge- and technology-intensive

MHT: medium-high technology

MNC: multinational company

NAFTA: North American Free Trade Agreement

NSF: National Science Foundation

OECD: Organisation for Economic Co-operation and Development

PTC: Production Tax Credit

R&D: research and development

RD&D: research, development, and demonstration

ROW: rest of world

S&E: science and engineering

S&T: science and technology

UK: United Kingdom

UN: United Nations

USPTO: U.S. Patent and Trademark Office

WTO: World Trade Organization

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CHAPTER 7

Science and Technology: Public Attitudes and Understanding

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Highlights

Interest, Information Sources, and Involvement

About 4 out of 10 Americans say they are “very interested” in new scientific discoveries, and 6 out of 10 Americans say they are “very interested” in new medical discoveries.

- Other science-related issues also interest many Americans, with 4 in 10 interested in environmental pollution and in the use of new inventions and technologies.

The Internet continues to grow as Americans’ primary source for science news and information seeking.

- The Internet has become Americans’ primary source of science and technology (S&T) information, with more than 5 in 10 Americans citing it as their primary source in 2016, compared with about 1 in 10 in 2001.
- Television and newspapers continued to be used less often as sources of S&T news and information in 2016.

Americans' attendance at traditional informal science sites is down or stable in recent years.

- About 5 in 10 Americans said they had visited a zoo or aquarium in 2016, similar to 2012 but down from nearly 6 in 10 in 2001.
- Smaller percentages of Americans, about 3 in 10, said they had visited a natural history museum in 2016 compared to previous years, and a similar proportion said they had visited an S&T center.

Public Knowledge about S&T

Americans correctly answered an average of 5.6 of 9 factual knowledge questions in 2016, a score similar to those in recent years.

- Americans with more formal education tend to provide a greater number of correct answers on science knowledge questions.
- About half of Americans agreed that human beings “developed from earlier species of animals,” the highest percentage seen for this question since 2001. Younger generations are more likely to answer the evolution question correctly.

About 6 in 10 Americans continue to correctly answer two multiple-choice questions dealing with probability in the context of medical treatment.

- About half of Americans could describe the best way to conduct a drug trial.
- About 3 in 10 Americans said they had a clear understanding of what is meant by a “scientific study” in 2016.

Public Attitudes about S&T in General

Public support for science appears to be stable. Americans continue to perceive far more benefits than harms from science and want government to fund scientific research.

- Most Americans, about 7 in 10, say they believe the benefits from science are greater than the harms, and almost all agree that S&T will create more opportunities for future generations.
- About half of Americans express concern that science is making life “change too fast.” This is similar to past highs.
- More than 8 in 10 Americans continue to say the government should fund basic scientific research, and about 4 in 10 continue to say we are spending “too little” to support such research.

Americans are more likely to have “a great deal of confidence” in leaders of the scientific community than in leaders of any group except the military.

- About 4 in 10 Americans express high levels of confidence in the scientific community, and more than 9 in 10 agree that scientists are helping to solve challenging problems facing the world.
- Since 2001, the percentage of Americans “strongly” agreeing that scientists are solving problems has risen from fewer than 2 in 10 Americans to almost 3 in 10.
- Although the medical community remains the third most respected group in America, the percentage of respondents who express “a great deal of confidence” in it has decreased (alongside confidence in most other institutions) since the 1970s and is now at a low of 36%.

Public Attitudes about Specific S&T-Related Issues

While Americans express less personal interest in the topic of environmental pollution, there is increasing concern about many specific environmental issues.

- Stated personal interest in environmental pollution has slowly declined since 1990, when more than 6 in 10 Americans said they were “very interested” in the topic. Only about 4 in 10 Americans gave this response in 2016.
- Despite the relatively low interest in the topic of environmental pollution in general, concern about specific environmental issues was high in 2016. Almost 8 in 10 Americans say they see water pollution as “extremely” or “very dangerous,” and more than 7 in 10 Americans say they see industrial air pollution as “extremely” or “very dangerous.” (Note that level of interest and level of concern are not necessarily equivalent. Individuals can be concerned about a particular issue but not be highly interested in that topic, especially in cases in which the topic has been on the public agenda for many years.)
- Levels of perceived danger from water and industrial pollution are substantially higher than they were in previous surveys.

Americans are divided on the severity and cause of climate change but concern has returned to previous highs.

- More than 6 in 10 Americans said they worried a “great deal” (45%) or a “fair amount” (21%) about “global warming.” Similar high levels of worry occurred in the early to mid-2000s.
- The highest recorded proportion of Americans ever—more than 6 in 10—say they believe that “global warming” is likely caused by humans.

- While 7 in 10 Americans recognize that "most" scientists believe warming is due to human activities, fewer than 2 in 10 know that almost all climate scientists attribute warming to human activity.
- Fewer than half of Americans think that "global warming" will pose a serious threat during their lifetime.

When given the choice, a majority of Americans say they would prefer to focus on non-fossil fuel alternatives.

- About 6 in 10 Americans say they would prioritize conservation over fossil fuel development; about 7 in 10 would focus on alternative energy over fossil fuel development.
- About 6 in 10 Americans in 2010 said they supported nuclear energy as one way to provide electricity in the United States. By 2016, about 4 in 10 expressed this view.

A substantial minority of Americans think genetically engineered foods are not safe, despite scientific consensus that such foods are no more dangerous than other foods.

- A recent consensus report by the National Academies of Sciences, Engineering, and Medicine concluded there is no substantiated evidence that current foods with genetically engineered ingredients are less safe than other foods.
- Despite the scientific consensus, more than 4 in 10 Americans say that "modifying genes" in crops is "extremely" or "very dangerous," a percentage that is higher than previous surveys. About 4 in 10 Americans also see genetically modified foods as less safe than other foods.

Many Americans view using stem cells from human embryos in medical research as "morally acceptable."

- Six in 10 Americans (60%) see using stem cells from human embryos as acceptable. This number has been relatively stable in recent years but is higher than earlier surveys.

Americans' views about animal testing have become less favorable over time.

- Gallup found that about 5 in 10 Americans now see animal testing as morally acceptable, down from more than 6 in 10 in 2010.

Introduction

Chapter Overview

The advancement and use of science and technology (S&T) are central to American life; S&T shapes what we do at home, at work, and in our communities. Many Americans produce new S&T at work (see Chapter 3), while others use S&T-based innovations to produce the goods and services that improve and reshape our lives. S&T gives us new opportunities to get healthy and stay healthy, including by influencing what and how we eat. It provides technologies that keep us connected and entertained. S&T often enters our conversations about daily life decisions and may stimulate us intellectually and emotionally. The centrality of S&T to American life means that Americans' attitudes about and understanding of S&T can reflect and affect the country's culture, well-being, and economy.

All technologies involve risks and benefits that may take time to become apparent. S&T discussions often center on these potential risks and benefits, as well as on moral issues raised by adopting scientific processes and technologies. Societies can do a better job of addressing potential concerns when the nature of these concerns is well understood and discussed (e.g., [NRC 1996, 2008]; [NASEM 2016a]). Americans' desire to seek potential benefits from S&T and deal with potential risks may affect what kinds of S&T are developed or used. For example, Americans must collectively decide how much of society's resources to devote to S&T research and development and where to devote those resources. Individuals may also choose where to focus their careers based on both their personal interests and their understanding of where they can make a meaningful contribution. Family members can also make decisions that may shape what young people learn, think, and feel about science.

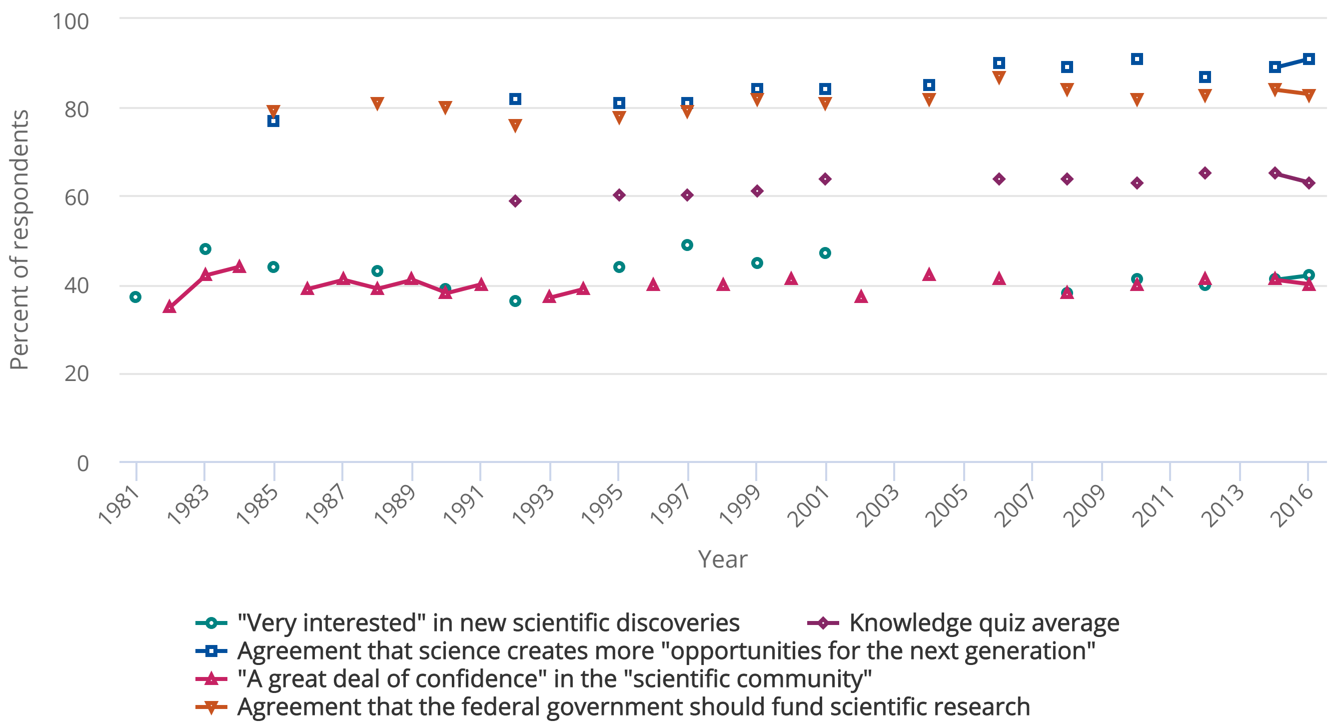
Given the centrality of S&T to the United States, this chapter presents indicators about interest in S&T news, where people encounter S&T in the media, trend data regarding knowledge of S&T, and indicators of people's attitudes about S&T-related issues. To put U.S. data in context, the chapter examines trend indicators for past years and comparative indicators for other countries, where reliable data are available.

A review of five key indicators in this chapter—interest in new scientific discoveries, basic scientific knowledge, belief that science creates opportunity, confidence in the scientific community, and support for science funding—indicates that Americans' overall attitudes about science are generally stable or becoming more positive, with some small fluctuations. The key indicators were chosen because data are available for a relatively long period for each indicator and because the indicators reflect the main themes raised in the chapter. Looking at these indicators together provides a sense of how Americans' overall attitudes and knowledge about S&T have changed over more than 30 years.

Specifically, the percentage of Americans saying that they are "very interested" in new scientific discoveries has been relatively stable in recent years, although the percentage is lower than in previous decades. Similarly, Americans' basic knowledge of science has also grown slightly over time. The percentages agreeing that S&T creates new opportunities and that it is important to fund scientific research have also been at relatively high levels in recent years compared with those from previous highs (Figure 7-1). Each of these five indicators is associated with education level, whether measured in terms of highest degree earned (Figure 7-2) or science- and math-specific courses taken in high school and college. In contrast, respondents' age and sex are generally unrelated or weakly related to these types of key indicators (Figure 7-2).

FIGURE 7-1

Key science and engineering knowledge and attitude indicators: 1981–2016



Note(s)

Data are not available for all knowledge and attitude indicators for all years. Includes the responses "strongly agree" and "agree" to the following statements: *Agreement that science creates more "opportunities for the next generation"* and *Agreement that the federal government should fund scientific research.* Data present the percentage of respondents who expressed a particular view, except in the case of the knowledge quiz average, which shows the estimated average percent of correct answers in each year.

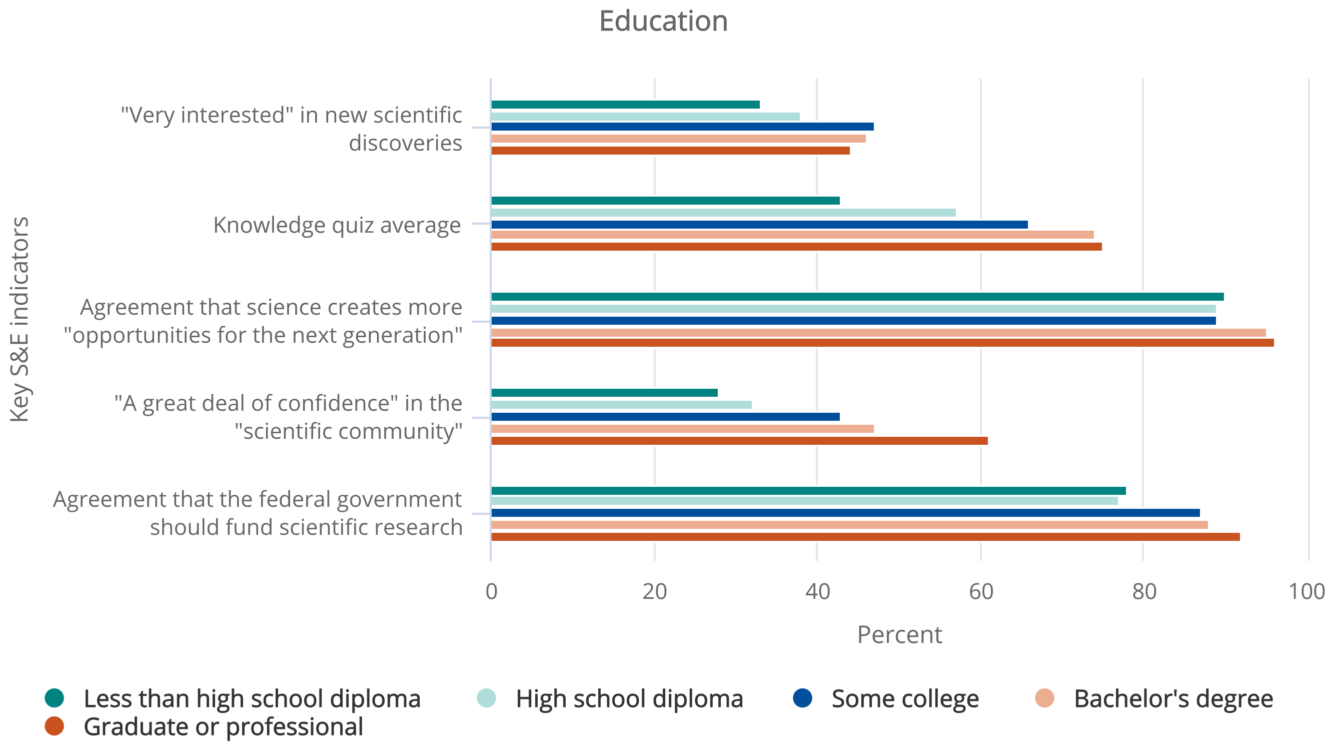
Source(s)

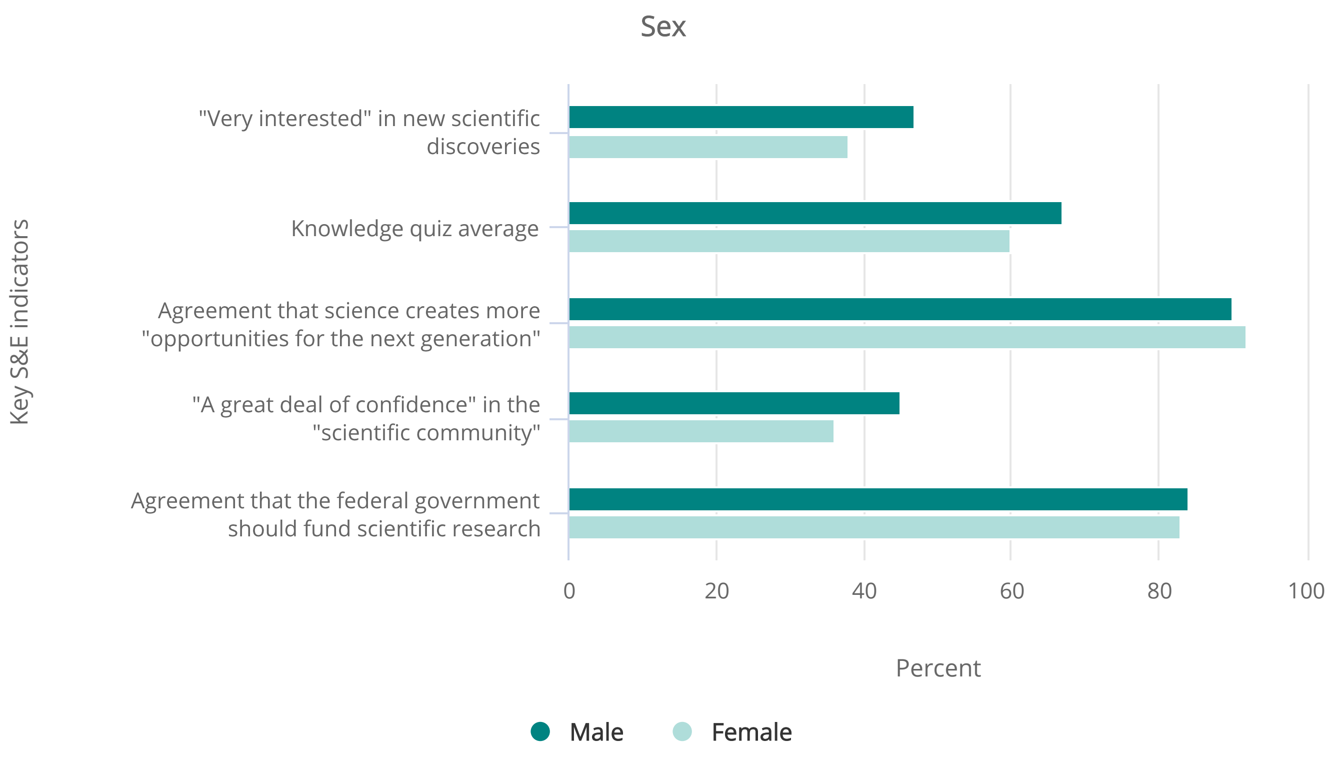
National Science Foundation, National Center for Science and Engineering Statistics, Survey of Public Attitudes Toward and Understanding of Science and Technology (1981–2001); University of Michigan, Survey of Consumer Attitudes (2004); NORC at the University of Chicago, General Social Survey (2006–16). See Appendix Tables 7-1, 7-8, 7-18, 7-22, and 7-28.

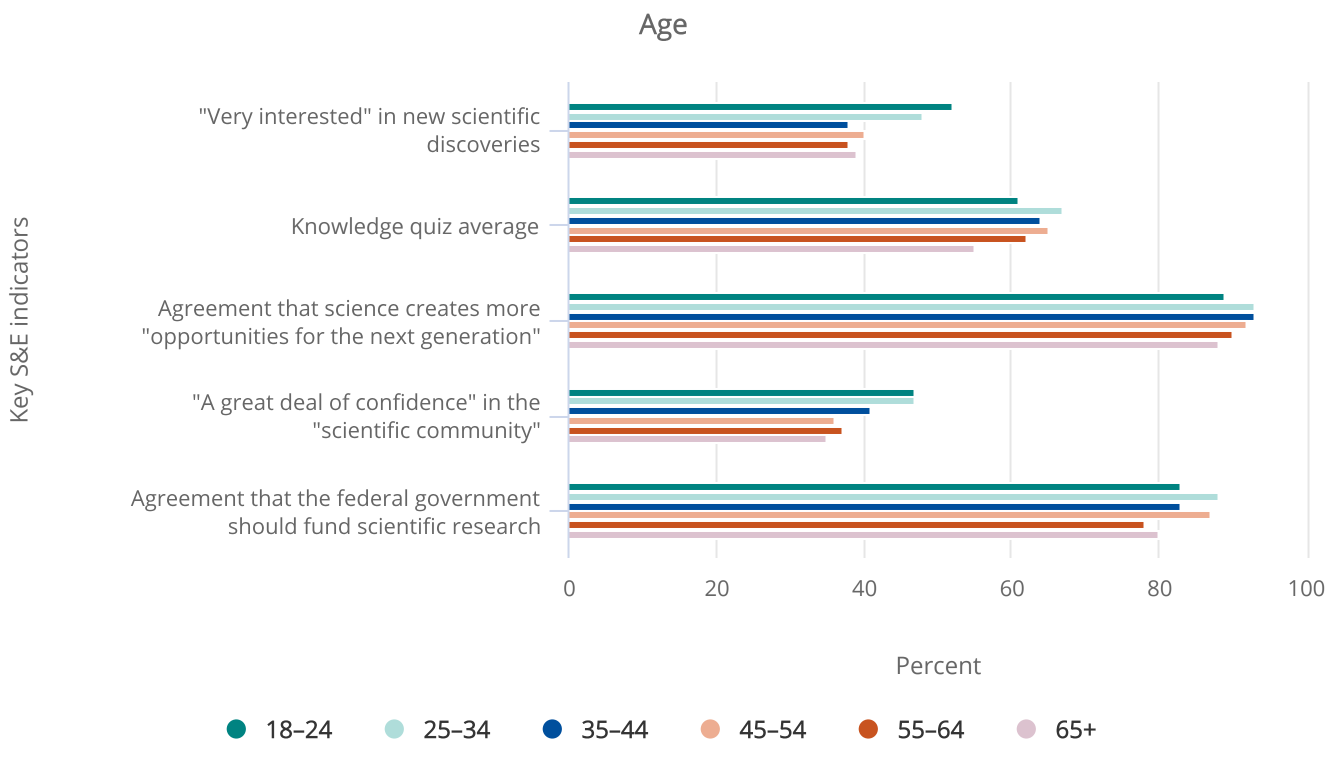
Science and Engineering Indicators 2018

FIGURE 7-2

Key science and engineering indicators, by selected respondent education, sex, and age: 2016




Sex
Key S&E indicators
"Very interested" in new scientific discoveries
Knowledge quiz average
Agreement that science creates more "opportunities for the next generation"
"A great deal of confidence" in the "scientific community"
Agreement that the federal government should fund scientific research
0
20
40
60
80
100
Percent
Male
Female


Age
Key S&E indicators
"Very interested" in new scientific discoveries
Knowledge quiz average
Agreement that science creates more "opportunities for the next generation"
"A great deal of confidence" in the "scientific community"
Agreement that the federal government should fund scientific research
0
20
40
60
80
100
Percent
18–24
25–34
35–44
45–54
55–64
65+

Note(s)

Includes the responses "strongly agree" and "agree" to the following statements: *Agreement that science creates more "opportunities for the next generation"* and *Agreement that the federal government should fund scientific research.*

Source(s)

NORC at the University of Chicago, General Social Survey (2016). See Appendix Tables 7-1, 7-10, 7-18, 7-21, and 7-29.

Science and Engineering Indicators 2018

Chapter Organization

The chapter is divided into four main sections. The first includes indicators of the public's ongoing engagement with S&T, including interest in S&T news, sources of information on S&T, and involvement in informal S&T activities. The second section reports on indicators of public knowledge, including trend measures of factual knowledge of S&T and people's understanding of the scientific process. The second section also includes results of survey experiments designed to better understand how question wording affects responses to knowledge questions on controversial issues. The third section presents data on attitudes indicating public support for S&T in general, including support for government funding of basic research and confidence in the leadership of the scientific community. The fourth section addresses attitudes on public issues in which S&T plays an important role, such as the environment, climate change, energy, nuclear power, and the use of animals in scientific research. It also includes indicators of public opinion about several active lines of research and new technologies, including genetically engineered food, stem cell research, and cloning.

A Note about Data and Terminology

The chapter emphasizes trends, patterns of variation within the U.S. population, and comparisons between public opinion in the United States and in other countries or regions. It reviews survey data from national samples with sound, representative sampling designs. The text focuses on the trends and demographic patterns in the data. Where possible, the focus is on new or updated data released since publication of *Science and Engineering Indicators 2016*.

The biennial General Social Survey (GSS), sponsored by the National Science Foundation (NSF), is a major source of data for this chapter. The GSS is a nationally representative, face-to-face survey on the attitudes and the behaviors of the U.S. population. The data are weighted to ensure representativeness. Questions about S&T information, knowledge, and attitudes were added to the GSS by NSF beginning in 2006. Comparable survey data were collected by telephone for NSF between 1982 and 2004. As with the GSS, data collected for NSF prior to 1982 come from face-to-face interviews. The changes in data collection methods over these years may affect comparisons over time. Such situations are highlighted in the text.

A range of other data sources is also used in the chapter, although only surveys involving probability-based samples are included. The primary sources of additional U.S. data include Gallup and the Pew Research Center. Like all survey data, the results reported in this chapter are subject to many sources of error—such as sampling error, response error, and measurement error due to question wording and random variation—that should be kept in mind when interpreting the findings. This report exercises caution in interpreting results from surveys that omit portions of the target population, have low response rates, or have topics that are particularly sensitive to subtle differences in question wording. Only differences that are statistically unlikely to have occurred by chance and that are substantive are emphasized in this chapter. The GSS typically uses face-to-face interviews, but most of the data from groups such as Gallup and the Pew Research Center use telephone samples (including both landlines and mobile phones) that inherently exclude those without telephones. The only Internet-based surveys used in the chapter are those collected by GfK and the Pew Research Center, both of which choose their panel members based on techniques similar to the telephone samples used by other organizations. For these, probability-based sampling typically is done using telephone and mail to invite people to be part of the panel, and then respondents are probabilistically selected for individual surveys. The additional step means that response rates are often lower than high-quality telephone surveys. Nevertheless, face-to-face surveys are believed to be the best way to obtain high response rates and to maximize participation by respondents with low income or education levels who may be less likely to respond to other types of surveys (see sidebar U.S. Survey Data Sources and sidebar International Survey Data Sources).

SIDEBAR

U.S. Survey Data Sources

▦ Table 7-A below describes U.S. surveys used in this chapter.

TABLE 7-A

U.S. survey data sources

(Data sources, selected details)

Sponsoring organization	Title	Years used	Questions used	Data collection method	Number of respondents; margin of error of general population estimates
Muhlenberg College and University of Michigan	National Surveys on Energy and Environment	2009–13, 2016–17	Climate change	Telephone interviews	*n* = 841 to 988; ±3% to 3.5%
National Science Foundation	Public Attitudes Toward and Understanding of Science and Technology (1979–2001); University of Michigan Survey of Consumer Attitudes (2004)	1979–2001, 2004	Information sources, interest, visits to informal science institutions, general attitudes, government spending attitudes, science and mathematics education attitudes, animal research attitudes	Telephone interviews	*n* = 1,574 to 2,041; ±2.47% to 3.03%
NORC at the University of Chicago	General Social Survey (GSS)	1973–2016	Government spending attitudes, confidence in institutional leaders	Face-to-face interviews, supplemented by telephone interviews	Government spending (2000–16): *n* = 1,390 to 2,256; ±2.5% to 3.9% Confidence in institutional leaders (1973–2016): *n* = 876 to 3,278; ±2.5% to 4.4%
NORC at the University of Chicago	GSS science and technology module	2006, 2008, 2010, 2012, 2014, 2016	Information sources, interest, visits to informal science institutions, general attitudes, government spending attitudes, science and mathematics education attitudes, animal research attitudes, nanotechnology awareness and attitudes, science knowledge	Face-to-face interviews, supplemented by telephone interviews	*n* = 1,864 to 2,256; ±2.5% to 3.3%

Sponsoring organization	Title	Years used	Questions used	Data collection method	Number of respondents; margin of error of general population estimates
National Survey of American Public Opinion on Climate Change	American Belief in Climate Change	2012	Climate change	Telephone interviews	*n* = 726; ±4.0%
Gallup Organization	Various ongoing surveys	1982–2017	Federal priorities, environmental protection, climate change, global warming, nuclear power, alternative energy, animal research, stem cell research, quality of science and mathematics education in U.S. public schools attitudes	Telephone interviews	*n* = ~1,000; ±3.0% to 4.0%
Pew Research Center for the People and the Press	General Public Science Survey, separate survey of American Association for the Advancement of Science members	2014	Public's and scientists' beliefs about science- and technology-related issues, benefits of science to well-being of society, animal research attitudes	Telephone interviews (survey of general public)	Public: *n* = 2,002; ±3.1% Scientists: *n* = 3,478; ±1.7%
Pew Research Center for the People and the Press	Media and political surveys (various)	1985–2016	Information sources, Internet use, national policy attitudes (environment, global warming, energy, stem cell research), government spending for scientific research attitudes, views of the news media, media believability	Telephone interviews	*n* = ~1,000 to 5,122; ±1.6% to 4.0%

Sponsoring organization	Title	Years used	Questions used	Data collection method	Number of respondents; margin of error of general population estimates
Yale Project on Climate Change Communication and the George Mason University Center for Climate Change Communication	Climate Change in the American Mind	2008–16	Climate change	Online (probability-based sample)	*n* = 1,010 to 2,164; ±3.0%

Note(s)

All surveys are national in scope and based on probability sampling methods. Statistics on the number of respondents and margin of error are as reported by the sponsoring organization. When a margin of error is not cited, none was given by the sponsor.

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International Survey Data Sources

Table 7-B below describes international surveys used in this chapter.

TABLE 7-B

International survey data sources

(Data sources, selected details)

Sponsoring organization	Title	Years used	Questions used	Data collection method	Number of respondents; margin of error of general population estimates
British Council, Russia	Survey of Public Attitudes Toward Science and Technology in Russia	2003	Various knowledge items	Paper questionnaires	*n* = 2,107
Council of Canadian Academies	Public Survey of Science Culture in Canada	2013	Various knowledge and attitude items, engagement, science skills	Landline and mobile phone (60%); Internet (40%)	*n* = 2,004; ±2.2%
Chinese Association for Science and Technology, China Research Institute for Science Popularization	Chinese National Survey of Public Scientific Literacy	2001, 2007, 2010, 2015	Various knowledge and attitude items, interest, occupational prestige, visits to informal science institutions	Face-to-face interviews	2001: *n* = 8,350 2007: *n* = 10,059 2010: *n* = 68,416 2015: *n* = 70,400
European Commission	Special Eurobarometer 224/ Wave 63.1: *Europeans, Science and Technology* (2005)	2005	Knowledge, trust in scientists, public support for basic research, other attitudes, visits to informal science institutions	Face-to-face interviews	*n* = 24,896 (EU total; member states: Austria: 1,034, Belgium: 1,024, Cyprus: 504, Czech Republic: 1,037, Denmark: 1,013, Estonia: 1,000, Finland: 1,007, France: 1,021, Germany: 1,507, Greece: 1,000, Hungary: 1,000, Ireland: 1,008, Italy: 1,006, Latvia: 1,034, Lithuania: 1,003, Luxembourg: 518, Malta: 500, Netherlands: 1,005, Poland: 999, Portugal: 1,009, Slovakia: 1,241, Slovenia: 1,060, Spain: 1,036, Sweden: 1,023, United Kingdom: 1,307)

Sponsoring organization	Title	Years used	Questions used	Data collection method	Number of respondents; margin of error of general population estimates
	Special Eurobarometer 224b/ Wave 64.3: *Europeans and Biotechnology in 2005: Patterns and Trends* (2006)	2005	Biotechnology attitudes	Face-to-face interviews	*n* = ~25,000; (EU total; member states: Austria: ~1,000, Belgium: ~1,000, Cyprus: ~1,000, Czech Republic: ~1,000, Denmark: ~1,000, Estonia: ~1,000, Finland: ~1,000, France: ~1,000, Germany: ~1,000, Greece: ~1,000, Hungary: ~1,000, Ireland: ~1,000, Italy: ~1,000, Latvia: ~1,000, Lithuania: ~1,000, Luxembourg: ~1,000, Malta: ~1,000, Netherlands: ~1,000, Poland: ~1,000, Portugal: ~1,000, Slovakia: ~1,000, Slovenia: ~1,000, Spain: ~1,000, Sweden: ~1,000, United Kingdom: ~1,000)
	Special Eurobarometer 300/ Wave 69.2: *Europeans' Attitudes Towards Climate Change* (2008)	2008	Climate change attitudes	Face-to-face interviews	*n* = ~26,661 (EU total; member states: Austria: 1,000, Belgium: 1,003, Bulgaria: 1,000, Cyprus: 504, Czech Republic: 1,014, Denmark: 1,005, Estonia: 1,006, Finland: 1,004, France: 1,040, Germany: 1,534, Greece: 1,000, Hungary: 1,000, Ireland: 1,004, Italy: 1,022, Latvia: 1,008, Lithuania: 1,021, Luxembourg: 501, Malta: 500, Netherlands: 1,041, Poland: 1,000, Portugal: 1,001, Romania: 1,019, Slovakia: 1,085, Slovenia: 1,003, Spain: 1,033, Sweden: 1,007, United Kingdom: 1,306)

Sponsoring organization	Title	Years used	Questions used	Data collection method	Number of respondents; margin of error of general population estimates
	Special Eurobarometer 340/ Wave 73.1: *Science and Technology Report* (2010)	2010	Science and technology attitudes and interest, support for basic research, animal research attitudes	Face-to-face interviews	*n* = ~26,671 (EU total; member states: Austria: 1,000, Belgium: 1,012, Bulgaria: 1,009, Cyprus: 502, Czech Republic: 1,043, Denmark: 1,006, Estonia: 1,004, Finland: 1,001, France: 1,018, Germany: 1,531, Greece: 1,000, Hungary: 1,017, Ireland: 1,007, Italy: 1,018, Latvia: 1,013, Lithuania: 1,026, Luxembourg: 503, Malta: 500, Netherlands: 1,018, Poland: 1,000, Portugal: 1,027, Romania: 1,060, Slovakia: 1,030, Slovenia: 1,004, Spain: 1,004, Sweden: 1,007, United Kingdom: 1,311)
	Special Eurobarometer 341/ Wave 73.1: *Europeans and Biotechnology in 2010: Winds of Change?* (2010)	2010	Nuclear energy, nanotechnology, emerging biotechnologies, synthetic biology, and genetically engineered foods attitudes	Face-to-face interviews	*n* = ~26,671 (EU total; member states: Austria: 1,000, Belgium: 1,012, Bulgaria: 1,009, Cyprus: 502, Czech Republic: 1,043, Denmark: 1,006, Estonia: 1,004, Finland: 1,001, France: 1,018, Germany: 1,531, Greece: 1,000, Hungary: 1,017, Ireland: 1,007, Italy: 1,018, Latvia: 1,013, Lithuania: 1,026, Luxembourg: 503, Malta: 500, Netherlands: 1,018, Poland: 1,000, Portugal: 1,027, Romania: 1,060, Slovakia: 1,030, Slovenia: 1,004, Spain: 1,004, Sweden: 1,007, United Kingdom: 1,311)

Sponsoring organization	Title	Years used	Questions used	Data collection method	Number of respondents; margin of error of general population estimates
	Special Eurobarometer 401/ Wave 6: *Responsible Research and Innovation (RRI) Science and Technology* (2013)	2013	Research, innovation, science, and technology attitudes	Face-to-face interviews	*n* = ~27,563 (EU total; member states: Austria: 1,022, Belgium: 1,000, Bulgaria: 1,018, Croatia: 1,000, Cyprus: 505, Czech Republic: 1,000, Denmark: 1,004, Estonia: 1,003, Finland: 1,003, France: 1,027, Germany: 1,499, Greece: 1,000, Hungary: 1,033, Ireland: 1,002, Italy: 1,016, Latvia: 1,006, Lithuania: 1,027, Luxembourg: 505, Malta: 500, Netherlands: 1,019, Poland: 1,000, Portugal: 1,015, Romania: 1,027, Slovakia: 1,000, Slovenia: 1,017, Spain: 1,003, Sweden: 1,006, United Kingdom: 1,306)
	Special Eurobarometer 419/ Wave 6: *Public Perceptions of Science, Research, and Innovation* (2014)	2014	Science, research, and innovation public attitudes	Face-to-face interviews	*n* = ~27,910 (EU total; member states: Austria: 1,005, Belgium: 1,025, Bulgaria: 1,033, Cyprus: 503, Croatia: 1,010, Czech Republic: 1,100, Denmark: 1,004, Estonia: 1,012, Finland: 1,017, France: 1,018, Germany: 1,511, Greece: 1,012, Hungary: 1,060, Ireland: 1,006, Italy: 1,014, Latvia: 1,016, Lithuania: 1,013, Luxembourg: 501, Malta: 501, Netherlands: 1,030, Poland: 1,082, Portugal: 1,009, Romania: 1,020, Slovakia: 1,007, Slovenia: 1,034, Spain: 1,009, Sweden: 1,050, United Kingdom: 1,308)
Gerbert Ruf Foundation, Mercator Foundation Switzerland, University of Zurich	Wissenschaftsbarometer	2016	Scientific knowledge, information sources	Telephone interviews	*n* = 1,000

Sponsoring organization	Title	Years used	Questions used	Data collection method	Number of respondents; margin of error of general population estimates
India National Council of Applied Economic Research	National Science Survey	2004	Various knowledge and attitude items, visits to informal science institutions	Face-to-face interviews	*n* = 30,255
Israeli Ministry of Science, Technology and Space	Perceptions and attitudes of the Israeli public about science, technology and space	2016	Various knowledge and attitude items	Online (Hebrew speakers); telephone interviews (Arabic speakers)	*n* = 501; ±4.4%
Japan Science and Technology Agency, Research Institute of Science and Technology for Society	Survey of Scientific Literacy	2011	Various knowledge items	Internet survey and interviews	*n* = 812 to 984
Korea Foundation for the Advancement of Science and Creativity (formerly Korea Science Foundation)	Survey of Public Attitudes Toward and Understanding of Science and Technology	2004, 2006, 2008, 2012	Interest, various knowledge and attitude items, visits to informal science institutions	Face-to-face interviews	*n* = 1,000; ±3.1%
Malaysian Science and Technology Information Center, Ministry of Science, Technology and Innovation	Survey of the Public's Awareness of Science and Technology: Malaysia	2014	Interest, awareness, various knowledge and attitude items, visits to informal science institutions	Face-to-face interviews	*n* = 2,653; ±2.71%

Sponsoring organization	Title	Years used	Questions used	Data collection method	Number of respondents; margin of error of general population estimates
Pew Global Attitudes Project, Pew Research Center	Global Attitudes Survey	2013	Climate change concerns	Depending on country, face-to-face interviews, telephone interviews	*n* = 1,002 (United States); ±3.5% *n* = 700 to 3,226 (38 other countries); ±3.1% to 7.7%
Wellcome Trust	Wellcome Trust Monitor	2015	UK public's interest in and attitudes towards biomedical science	Face-to-face interviews	*n* = 1,524

EU = European Union; UK = United Kingdom.

Note(s)

All surveys are national in scope and based on probability sampling methods. Statistics on the number of respondents and margin of error are as reported by the sponsoring organization. When a margin of error is not cited, none was given by the sponsor.

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Another important limitation is that up-to-date, high-quality data are not always available. In some cases, there are only single surveys covering a particular period, large gaps between data collection years, or only a small number of questions on any given topic. This challenge is particularly acute when it comes to international data. There have been many surveys on S&T in Europe, but these are not conducted as regularly as the GSS, and data from Africa and South America are especially rare. As noted, the current chapter focuses on data that have become available after the preparation of the 2016 *Indicators* report. Earlier data can be found in past editions of *Indicators* (e.g., [NSB 2016]). A summary is also available in Bauer, Shukla, and Allum (2012) of relevant data (up to 2006) from numerous countries and regions. Moreover, even in cases in which international comparisons attempt to compare identical questions, the responses may not be wholly comparable because of cultural differences in the meaning of the questions.

Throughout this chapter, the terminology used in the text reflects the wording in the corresponding survey questions. In general, survey questions asking respondents about their primary sources of information, interest in issues in the news, and general attitudes use the phrase *science and technology*. Thus, *S&T* is used when discussing these data. Survey questions asking respondents about their confidence in institutional leaders, the prestige of occupations, and their views on different disciplines use terms such as *scientific community*, *scientists*, *researchers*, and *engineers*, so *science and engineering* (*S&E*) is used when appropriate for examining issues related to occupations, careers, and fields of research. Although science and engineering are distinct fields, national survey data that make this distinction are scarce (see, however, [NSB 2014:7-35]). The term *Americans* is used throughout to refer to U.S. residents included in a national survey; equivalent terms (e.g., *Canadians*) are used for residents of other countries. However, not all respondents were necessarily citizens of the countries in which they were surveyed. When discussing data collected on behalf of NSF, the term *recent* is used to refer to surveys conducted since 2006, when data collection shifted to the GSS.

Interest, Information Sources, and Involvement

Trends in Americans' understanding of and attitudes about topics such as S&T depend, in part, on how much exposure they get to such content throughout their lives, as well as how much attention they pay to such content (Slater, Hayes, and Ford 2007). Exposure and attention to S&T can make residents more informed, shape their attitudes, and help them make decisions that are better for themselves, their families, and their communities. Media use may also foster a desire to seek and consider new information (Rimal, Flora, and Schooler 1999). All of these issues are interconnected and are meant to provide indicators of where S&T fits in peoples' lives.

This section reviews overall expressed interest in media reports about S&T and where the public turns to within the news media when looking for S&T information. It concludes with indicators of personal involvement in S&T-related activities through visits to museums and other cultural institutions.

Public Interest in S&T

U.S. Patterns and Trends

Most Americans continue to say they are interested in S&T. In 2016, 42% said they were "very interested" in new scientific discoveries, and another 42% said they were "moderately interested" (Figure 7-3). Similarly, 42% said they were "very interested" in use of new inventions and technologies, with 46% "moderately interested." Medical discoveries drew the highest interest: 60% said they were "very interested," and another 35% said they were "moderately interested."

Americans expressed relatively low interest in two other science topics. About a quarter (24%) said they were "very interested" in space exploration (44% "moderately interested"). This puts space exploration near the bottom of the list of subjects asked about in the survey, similar to agricultural and issues (21% “very interested” in 2016). Beyond science, Americans were “very interested” in local school issues (44%), economic issues and business conditions (39%), and military and defense policy (34%).

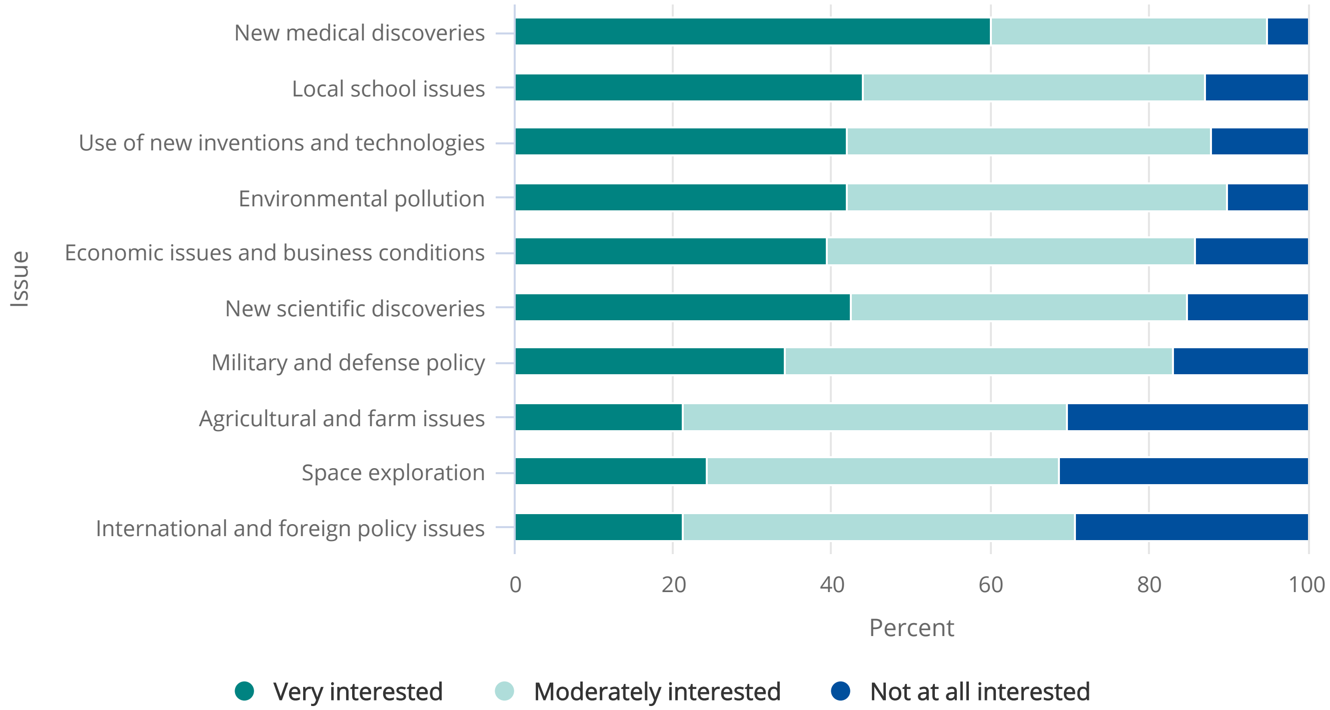
Although generally down from previous highs, science-related interest has been fairly stable in recent years, with the exception of interest in environmental pollution, which has continued a slow decline over several decades (Figure 7-4). In 1990, 64% of respondents said they were “very interested” in the topic of environmental pollution, but this fell to 42% in 2016. Interest in medical discoveries is also lower than it was in previous decades, although it has been relatively stable in recent years (Figure 7-4; Appendix Table 7-1 provides data by selected issues, and Appendix Table 7-2 provides data by demographic groups). It is not clear from the data as to why respondents have been less likely to express interest in environmental pollution over time. In contrast, the discussion of specific environmental issues later in this chapter indicates that concern about the environment is relatively high in historical terms. The term *pollution* may have become less salient as public discussion has turned to issues such as climate change, or the change may have something to do with the fact that environmental pollution may be perceived as a negative topic, whereas the other subjects may be seen as relatively neutral or positive. Also, while interest in environmental pollution has steadily declined, concern about specific environmental issues has gone up and down several times in recent decades. (Note that “level of interest” and “level of concern” are not necessarily equivalent.) Individuals can be concerned about a particular issue but not be highly interested in that topic (or the broader underlying issue), especially in cases in which the topic has been on the public agenda for many years.

Interest in science topics—as with most other topics—is associated with education levels, as well as with mathematics and science course taking. Women tend to be more interested in medical discoveries (63% for women, compared to 55% for men), whereas men are more interested in other S&T topics. For example, 47% of men said they were very interested in new scientific discoveries, compared to 38% of women (Appendix Table 7-2).

Questions about interest may greatly depend on the specific wording used to describe the subject and on the type of response that survey participants are allowed to select. Although new scientific discovery ranks in the middle of a group of issues in the GSS data (42% were “very interested”), a Pew Research Center study (Mitchell et al. 2016) found that only 16% of Americans said they followed news about S&T in the newspaper, on television, radio, or the Internet “very closely.” This response was similar to the percentage of Americans who say they followed sports “very closely” but was about half of the number who said they followed government and politics (30%) or crime (27%) “very closely.”

FIGURE 7-3

Public interest in selected issues: 2016



Note(s)

Responses to the following: *There are a lot of issues in the news, and it is hard to keep up with every area. I'm going to read you a short list of issues, and for each one I would like you to tell me if you are very interested, moderately interested, or not at all interested.* Responses of "don't know" are not shown. Percentages may not add to 100% because of rounding.

Source(s)

NORC at the University of Chicago, General Social Survey (2016). See Appendix Table 7-1.

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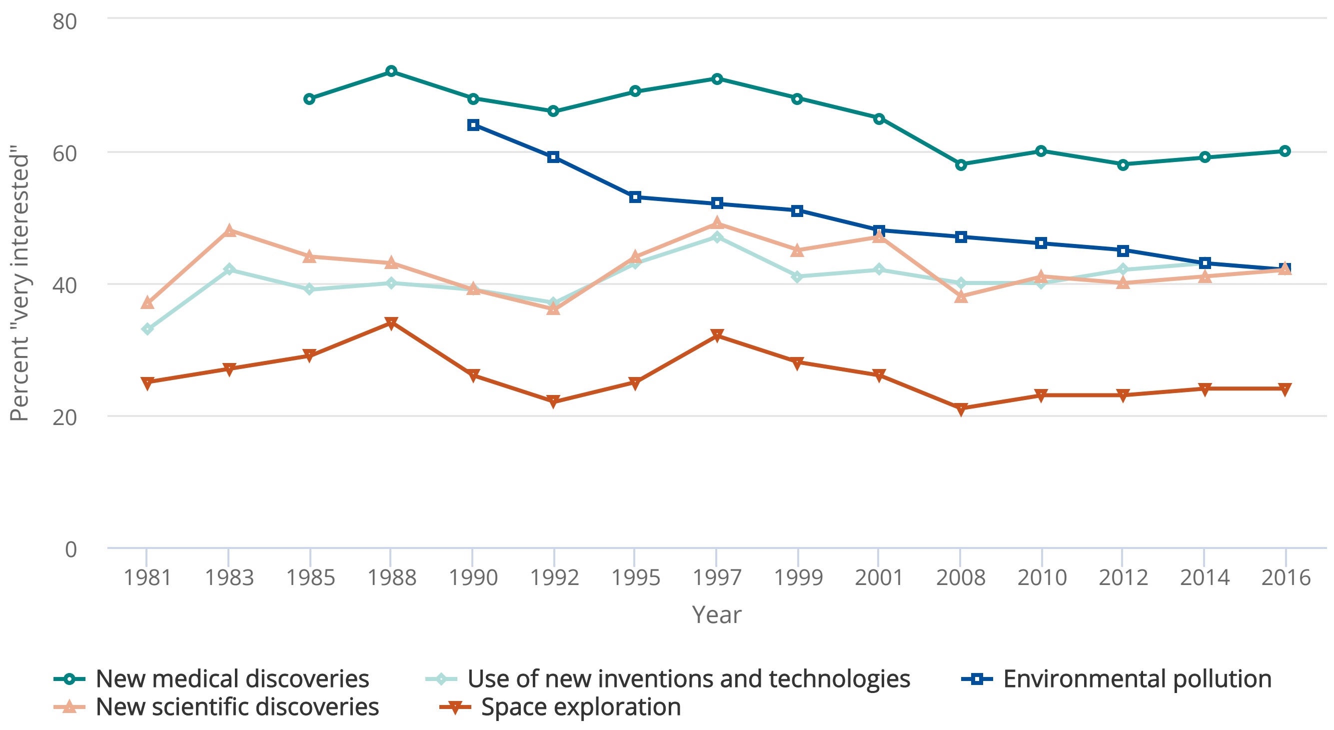
FIGURE 7-4

Public interest in selected science-related issues: 1981–2016



Note(s)

Data are not available for all years. Responses to the following: *There are a lot of issues in the news, and it is hard to keep up with every area. I'm going to read you a short list of issues, and for each one I would like you to tell me if you are very interested, moderately interested, or not at all interested.* Figure shows only "very interested" responses.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Survey of Public Attitudes Toward and Understanding of Science and Technology (1981–2001); NORC at the University of Chicago, General Social Survey (2008–16). See Appendix Table 7-1.

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International Comparisons

Outside of the United States, a majority of residents of other countries for which there are 2015 or 2016 data also typically report high levels of interest in various science topics—particularly, health. Direct comparison is problematic, but the available evidence suggests that the United States often has similar or higher levels of interest in science topics than other countries. In Asia, for example, a large-scale 2015 survey of Chinese respondents found that 93% said they were interested in health topics, which is similar to the 95% of Americans who expressed high or moderate interest. Similarly, 78% of Chinese respondents said they were interested in new scientific discoveries, compared to 84% of Americans who expressed interest. For new inventions and technologies, 75% of Chinese said they were interested in new inventions and technologies, compared to 88% of

Americans who expressed some interest (CRISP 2016). In Europe, expressed interest appears to be lower than in the United States or China. For the United Kingdom (UK), the Wellcome Trust (2016) found that 77% of UK residents said they were interested in medical research, similar to previous years, and 63% of UK residents said they were interested in hearing directly from scientists about the scientists' research. In Germany in 2016, 41% said they had a considerable interest in scientific topics, and an additional 43% of Germans said they had some interest (Wissenschaft im dialog 2016). In Switzerland, about half chose either 5 (20%) or 4 (31%) on a 5-point measure that asked them to describe their interest in science and research as somewhere between "no interest at all" and an "enormous amount of interest" (Schafer and Metag 2016). In northern Europe, about 75% of Finns said they were interested in following news about medicine, 73% said they were interested in general science news, and 68% said they were interested in environmental news (FSSI 2016). Science interest in South America appears to be somewhat lower, with 58% of respondents in Chile saying in 2016 that they were interested in science (CONICYT 2016) and 52% of Argentinians saying that they were interested in S&T. About 70% of Argentinians, however, said they were interested in medicine and health (MCTIP 2015).

Further back, a 2013 pan-European study found that 53% of Europeans were "very interested" or "fairly interested" in S&T versus 87% of Americans, who were "very interested" or "moderately interested." The 27 European countries surveyed display a broad range of interest levels, with a high of 77% in Sweden and lows of 34% and 35% in the Czech Republic and Bulgaria, respectively (European Commission 2013).

S&T Information Sources

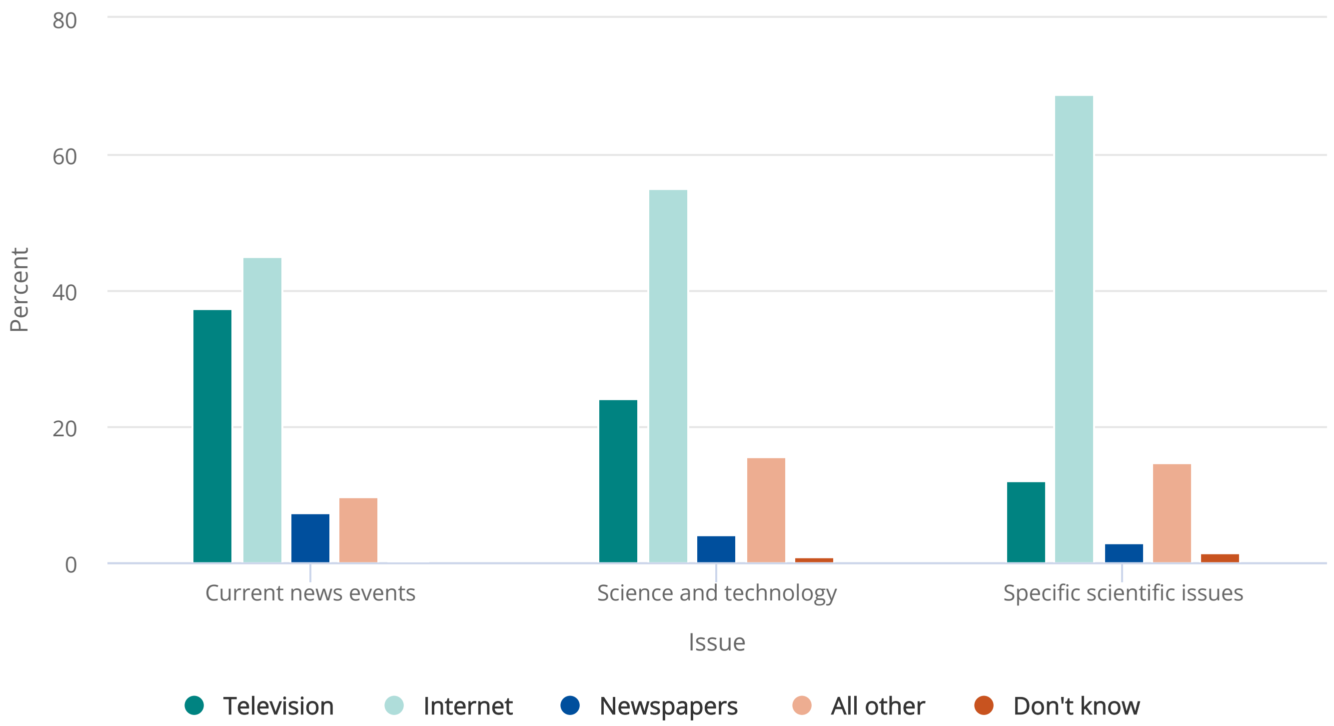
U.S. Patterns and Trends

The news media environment continues to change as new organizations emerge, existing organizations disappear or merge, and journalistic routines change in response to economic, social, and technological forces. The available data show clear trends in the sources Americans say they use to get news about current events and S&T.

As background, according to the GSS data, daily newspaper readership declined from 67% in 1972 to 25% in 2014 and 20% in 2016. The percentage who say they never read a newspaper climbed from about 4% in 1972 to 29% in 2014 and 38% in 2016. The available question does not specifically ask respondents about whether they consider reading a newspaper online when responding to this question; therefore, it is difficult to know if the drop in news readership represents a drop or a shift toward online newspaper reading. Pew Research Center (Mitchell et al. 2016) findings suggest that about three quarters (77%) of Americans follow the national news "very closely" (33%) or "somewhat closely" (44%). This suggests that many Americans continue to get news, though not from traditional print newspapers (📊Figure 7-5). Also, whereas the GSS reports that newspaper reading has declined, the data suggest that television viewing time has stayed stable in the face of technological change. According to the GSS, Americans said they watched about 2.9 hours of television per day in 2016, and this number has stayed between a low of about 2.8 hours (multiple years) and a high of about 3.2 hours (multiple years) per day since 1975.

FIGURE 7-5

Primary source respondents used to learn about current news events, science and technology, and specific scientific issues: 2016



Note(s)

"All other" includes radio, magazines, books, government agencies, family, and friends or colleagues.

Source(s)

NORC at the University of Chicago, General Social Survey (2016). See Appendix Table 7-3 through Appendix Table 7-5.

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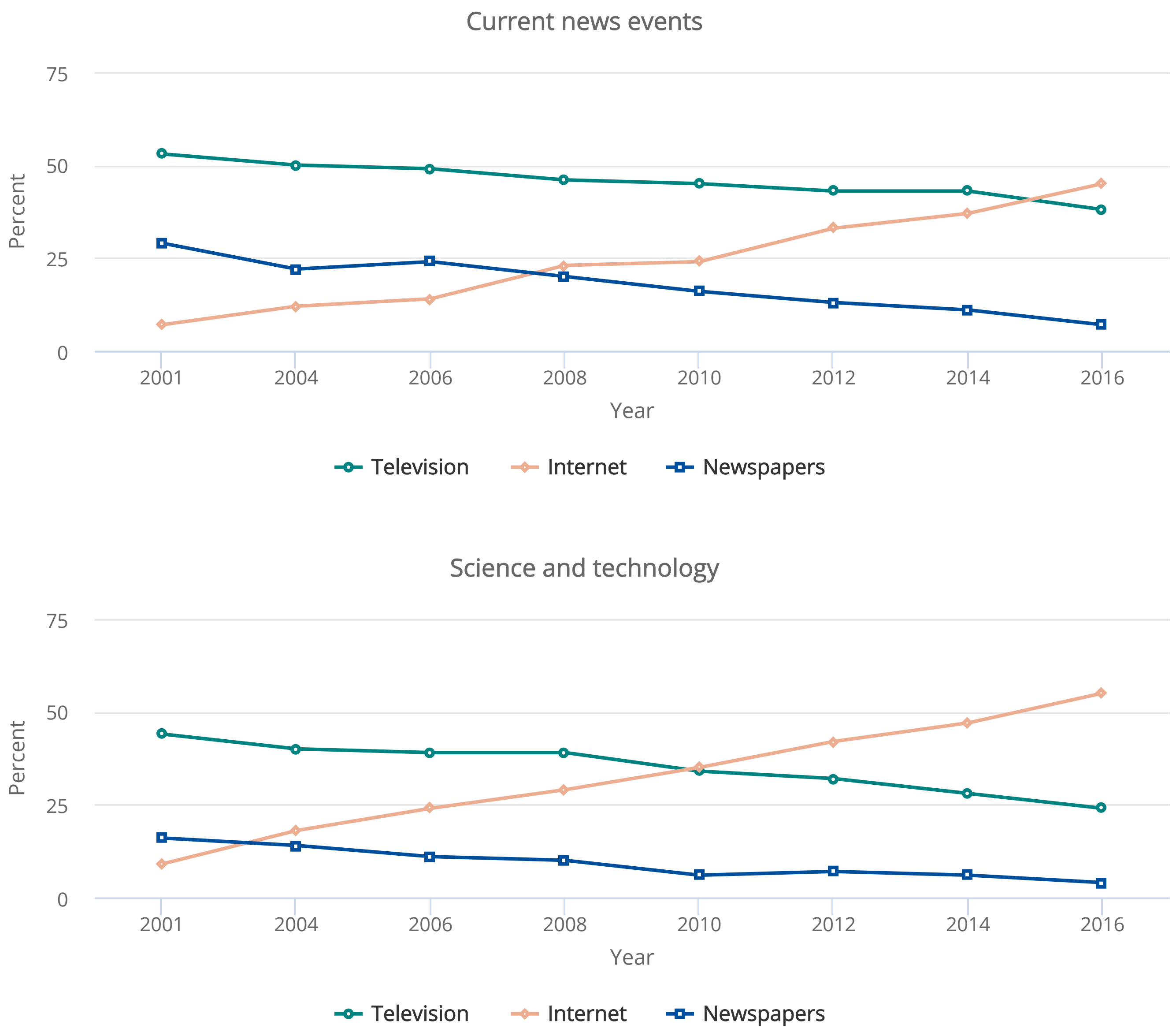
With regard to source, for news about general current events, 45% of Americans said that the Internet was their primary source of information about current events in 2016, up from 37% in 2014 (Figure 7-6). This means the Internet has now surpassed television as Americans' main source of news. About 37% of Americans said television was their primary source of information in 2016, down from 43% in 2014. Newspapers also dropped to 7% in 2016 from 11% in 2014 (Figure 7-6; Appendix Table 7-3). The percentage of Americans who report getting information about current events from the Internet has increased steadily since about 2001, and the percentages using newspapers and television for current events have declined.

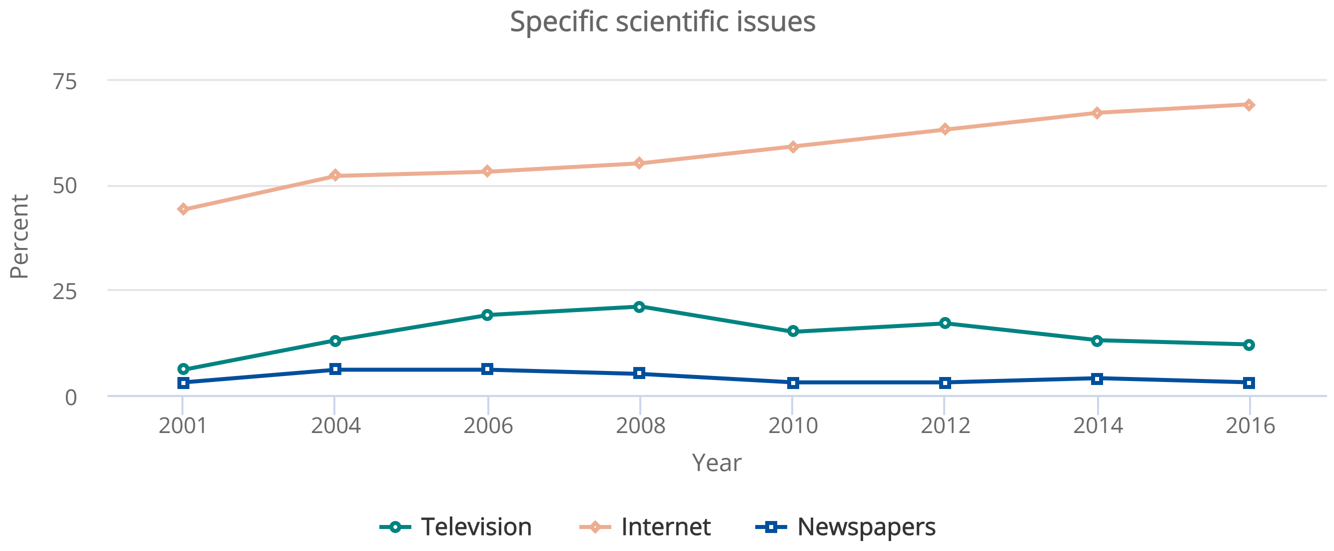
For news specifically about S&T, Americans are also more likely to rely on the Internet than on television. In 2016, 55% of Americans cited the Internet as their primary source of S&T information, up from 47% in 2014. This percentage has grown steadily since 2001, when the Internet was added to the survey and 9% named it as their primary source of S&T news. Reliance on television has continued to drop. About 24% of Americans reported that television was their primary source of S&T news in 2016, down from 28% in 2014. In 2016, 4% of Americans said that they get their S&T information from newspapers, compared with 6% in 2014 (Figure 7-6; Appendix Table 7-4). Of the 55% who said they go online for S&T information, 36% (i.e., 20% overall) said that they use a search engine such as Google to seek information, while 45% (or 25% overall) said they use online newspapers (25%), online magazines (14%), or other online news sites (6%). Of course, Google searches might lead people to one of these other sources of information.

The Internet has also been the most common resource that Americans say they would use to seek information about specific scientific issues, and this has continued to grow since at least 2001 (Figure 7-6). In 2016, 69% said they would go online to find information about a specific S&T issue. Another 12% said they would turn to television, and just 3% said they would use newspapers. In 2014, 67% said they would use the Internet, up from 63% in 2012 (Figure 7-6).

FIGURE 7-6

Primary source respondents used to learn about current news events, science and technology, and specific scientific issues: 2001–16





Specific scientific issues

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Survey of Public Attitudes Toward and Understanding of Science and Technology (2001); University of Michigan, Survey of Consumer Attitudes (2004); NORC at the University of Chicago, General Social Survey (2006–16). See Appendix Table 7-3 through Appendix Table 7-5.

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Different subgroups of Americans tend to rely on different sources of information. Generally, higher levels of education and income are associated with relatively higher levels of Internet and newspaper use, whereas respondents with lower levels of education and income are more likely to say they rely on television. For example, 39% of those whose highest education level is high school say they use the Internet for current event news, while 56% of those with bachelor's degrees give this response. In contrast, 42% of those whose highest level of education is high school say television is their primary source of current event news, compared to 26% of those with bachelor's degrees. Newspaper reliance is more common for relatively older respondents, and Internet reliance is more common for relatively younger and higher-earning respondents. In 2016, almost no respondents under the age of 24 said that newspapers were their primary source of S&T news, although this does not mean they may not have received science news written for newspapers and published online. Television use is also somewhat less common for younger respondents (Appendix Table 7-3, Appendix Table 7-4, and Appendix Table 7-5).

International Comparisons

International patterns of media sources for news appear to differ from those in the United States, especially in the continuing importance of television. However, different question wording and the fact that many international surveys allow specifying more than one news source prevent direct comparison. For example, in China, 93% of respondents said that television was a main source for S&T information, while 53% said the Internet and 39% said newspapers were among their main sources (CRISP 2016). In the UK, individuals were more likely to report that they had heard about or seen medical research on television (43%) than through a website or newspaper (21% and 19%). However, 90% said they had looked for information about medical research online. In Germany, 67% said they often (33%) or sometimes (34%) get information about science and research from television, compared to 54% for newspapers and magazines and 44% for the Internet (Wissenschaft im dialog 2016). In Finland, 81% said television was "very important" or "fairly important" as a source of science and research information, compared to 71% who said that newspapers were personally important and 70% who indicated the Internet was important (FSSI 2016). In South America, 39% of Chileans said they always or almost always watch S&T or nature programs on television, 23% said they always or almost always use the Internet to search for science information, and 19% said the same about reading such information in newspapers (CONICYT 2016).

Involvement

U.S. Patterns and Trends

Many U.S. residents may encounter S&T through America's rich and diverse informal science and cultural institutions (Bell et al. 2009).[1] In 2016, zoos and aquariums were the most popular type of informal science institutions, with 48% of Americans saying they had visited such a facility in the previous year. This proportion has gradually declined from about 58% in 2001 and 52% in 2008. Attendance levels are now back to where they were through much of the 1980s and 1990s (Appendix Table 7-6). Beyond zoos and aquariums, 30% of Americans said they had visited a natural history museum in the previous year, and 26% said they had visited an S&T museum. These percentages are similar to those for 2012.

Americans with more years of formal education were more likely than others to visit informal science sites, as were those in higher income brackets (Appendix Table 7-7). In general, visits to informal science institutions peak during the years in which people are raising their children. About 73% of those in the 35–44 age group reported visiting at least one informal science institution in the previous year, compared to 68% in the 18–24 age group and 35% of those in the 65 and over age group. One limitation of the data is that they do not speak to the quality of the institution visited and the full range of informal S&T activities that individuals may participate in during a given year (e.g., science festivals, maker days, stand-alone talks, citizen science activities).

Examples of natural history museums include the Smithsonian's National Museum of Natural History in Washington, District of Columbia, the Field Museum in Chicago, Illinois, the Denver Museum of Nature and Science in Colorado, and the Fernbank Museum of Natural History in Atlanta, Georgia. An S&T museum can include museums or centers such as the Smithsonian's National Air and Space Museum in Washington, District of Columbia, the Center of Science and Industry in Columbus, Ohio, the Sci-Port Discovery Center in Shreveport, Louisiana, or the Exploratorium in San Francisco, California (ASTC 2017).

International Comparisons

Other countries tend to have a similar or lower likelihood of having participated in the informal science activities for which there are U.S. data. In 2015, 54% of Chinese respondents said they had visited a zoo or aquarium in the last year, 22% said they had visited a natural history museum, and 23% said they had visited an S&T museum (CRISP 2016). About 46% of Germans said they had visited a zoo or aquarium, and 40% said they had been to a science or technology museum in the last year, although the German survey did not differentiate between natural history museums and more S&T-focused museums (Wissenschaft im dialog 2016). In the UK, 36% said they had visited a zoo or aquarium, and 20% said they had been to a science museum or an S&T museum or center (Wellcome Trust 2016). About 31% of Chileans said they had been to a zoo or aquarium in the last year, and 15% said they had been to an S&T museum (CONICYT 2016).

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[1] People become involved with S&T through many kinds of nonclassroom activities beyond attending informal science institutions. Examples of such activities include participating in government policy processes, going to movies that feature S&T, attending talks or lectures, bird watching, and building computers. *Citizen science* is a term used for activities by citizens with no specific science training who participate in the research process through activities such as observation, measurement, or computation. Nationally representative data on this sort of involvement with S&T are unavailable.

Public Knowledge about S&T

Science and Engineering Indicators has been reporting results of assessments of Americans' knowledge about S&T since 1979. Initial indicators focused on the proper design of a scientific study and whether respondents viewed pseudoscientific belief systems, such as astrology, as scientific. The questions also examined understanding of probability, and questions meant to assess understanding of basic scientific facts were added in the late 1980s and early 1990s (Miller 2004). These later factual questions—called here the *trend factual knowledge* questions—remain the core of one of the only available data sets on trends in adult Americans' knowledge of science (NASEM 2016c).

Although tracking indicators on science knowledge is an important part of this chapter, it is also important to recognize that research has shown that science literacy only has a small—though meaningful—impact on how people make decisions in their public and private lives (see, e.g., [Allum et al. 2008]; [Bauer, Allum, and Miller 2007]; [NASEM 2016c]; [NSB 2012:7–27]). It is also, however, clear that such knowledge need not result in accepting the existence of a scientific consensus or a policy position that such a consensus might suggest (Kahan et al. 2012). One challenge of measuring the effect of science literacy is that processes—such as formal and informal education—through which knowledge is gained also contribute to interest in S&T and confidence in the S&T community. These same processes might also affect general and specific attitudes about science. The National Academies of Sciences, Engineering, and Medicine also recently highlighted that science literacy is largely a function of general (or "foundational") literacy and that more focus should be put on the ability of groups to use science to make high-quality decisions (NASEM 2016c). In this regard, it should be recognized that the science literacy of individuals is unequally distributed across societies, so that some groups or communities are able to make use of science when needed while others are not because they may not have access to resources such as local expertise (e.g., community members who are also scientists, engineers, doctors).

It is also noteworthy that the current survey uses a relatively small number of questions compared to all the scientific subjects about which someone could be asked and thus cannot be said to represent a deep measurement of scientific knowledge. Given such concerns, the 2010 version of *Indicators* included responses to an expanded list of knowledge questions and found that people who "answered the additional factual questions accurately also tended to provide correct answers to the trend factual knowledge questions included in the GSS" (NSB 2010:7-20). The trend questions used in this report thus likely represent a reasonable indicator of basic science knowledge. The goal when designing these questions was to assess whether an individual likely possessed the knowledge that might be needed to understand a quality newspaper's science section (Miller 2004).

There is, however, evidence that the current trend measures may be better at differentiating low and medium levels of knowledge than they are at differentiating those with higher levels of knowledge (Kahan 2016). More generally, considering the limitations of using a small number of questions largely keyed to knowledge taught in school, generalizations about Americans' knowledge of science should be made cautiously.

Another issue is that, although the focus in *Indicators* is on assessing knowledge about scientific facts and processes, it could also be important to assess knowledge about the institutions of science and how they work—such as peer review and the role of science in policy discussions (Toumey et al. 2010). Others have similarly argued that the knowledge needed for citizenship might be different from what might be needed to be an informed consumer or to understand the role of science in our culture (Shen 1975). Science literacy can also be understood as the capacity to use scientific knowledge, to identify questions, and to draw evidence-based conclusions in order to understand and help make decisions about the natural world and the changes made to it through human activity (OECD 2003:132–33).

The degree to which respondents demonstrate an understanding of basic scientific terms, concepts, and facts; an ability to comprehend how S&T generates and assesses evidence; and a capacity to distinguish science from pseudoscience have become widely used indicators of basic science literacy. The 2016 GSS continues to show that many Americans provide multiple incorrect answers to basic questions about scientific facts and do not apply appropriate reasoning strategies to questions about selected scientific issues. Residents of other countries, including highly developed ones, rarely appear to perform better when asked similar questions.

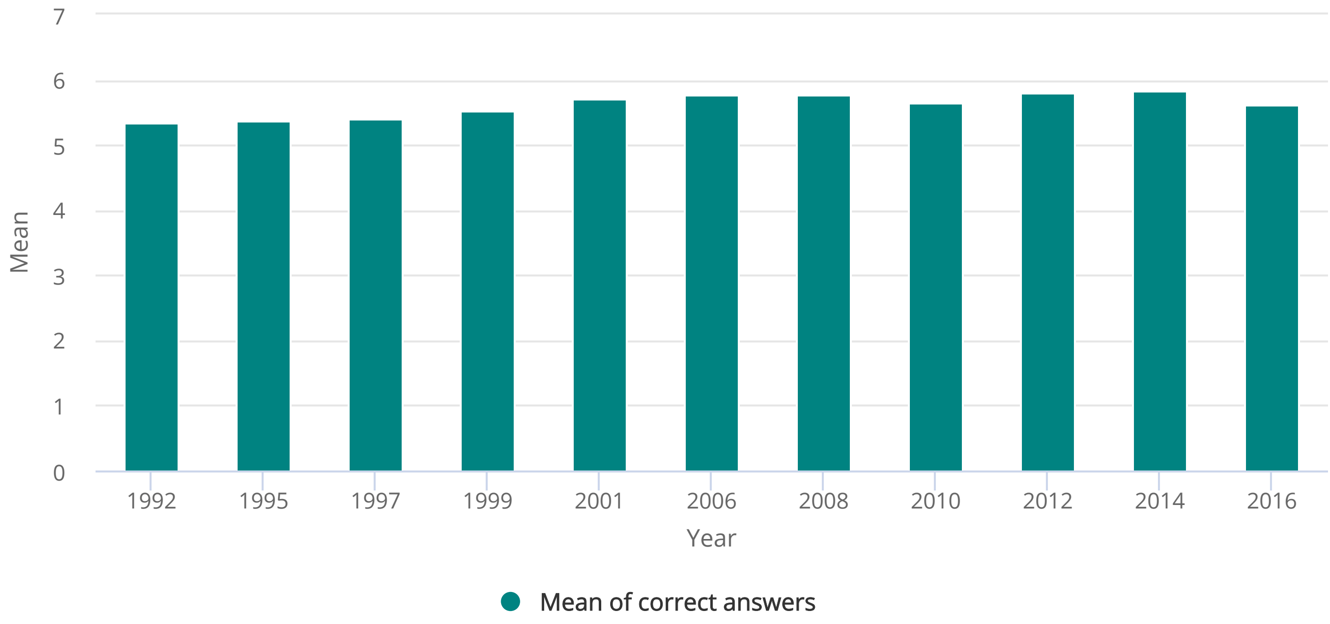
Understanding Scientific Terms and Concepts

U.S. Patterns and Trends

In 2016, Americans correctly answered an average of 5.6 of the 9 true-or-false or multiple-choice items (63%) from NSF's factual knowledge questions. This score is not substantially lower than the 2012 and 2014 scores of 5.8 and is thus generally consistent with recent years (📊Figure 7-7; Appendix Table 7-8). Two additional true-or-false questions about the theory of evolution and the Big Bang, which are not included in the 9-item measure, are also discussed subsequently.

FIGURE 7-7

Mean number of correct answers to trend factual knowledge of science scale: 1992–2016



Note(s)

Mean number of correct answers to nine questions included in trend factual knowledge of science scale; see Appendix Table 7-2 for explanation and list of questions. See Appendix Table 7-8 for percentage of questions answered correctly. See Appendix Tables 7-9 and 7-10 for responses to individual questions.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Survey of Public Attitudes Toward and Understanding of Science and Technology (1992–2001); NORC at the University of Chicago, General Social Survey (2006–16).

Science and Engineering Indicators 2018

The public's measured level of factual knowledge about science has not changed much over the past two decades. Since 2001, the average number of correct answers to a series of 9 questions for which fully comparable data have been collected has ranged from 5.6 to 5.8 correct responses—a difference that is small enough that it could have occurred by chance, given the sample size—although scores for individual questions have varied somewhat more over time (Figure 7-8; Appendix Table 7-8, Appendix Table 7-9, and Appendix Table 7-10).[1] The Pew Research Center (2013) used several of the same questions in a 2013 survey and received similar results.

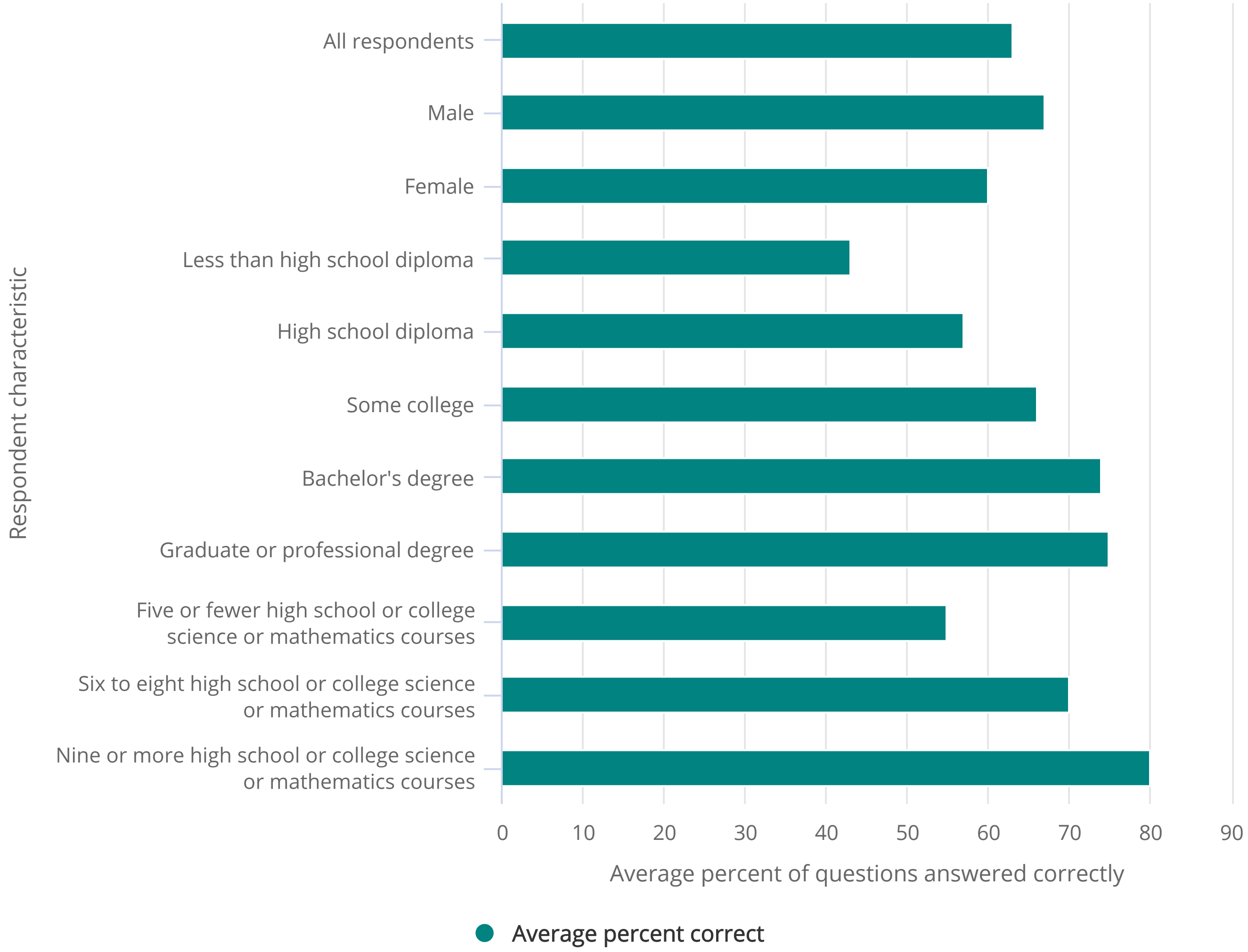
Within the GSS data, trend factual knowledge of science is strongly related to individuals' level of formal schooling and the number of science and mathematics courses completed (Figure 7-8; Appendix Table 7-8 and Appendix Table 7-10). Those who had not completed high school answered 43% of the 9 questions correctly, whereas those for whom a bachelor's degree was their highest academic credential answered 74% of the questions correctly. Similarly, Americans who took five or fewer high school or college science or mathematics courses answered 55% of the questions correctly, whereas those who had taken nine or more courses answered 80% correctly (Appendix Table 7-8).

Although NSF survey data showed a large gap in scientific knowledge between the top-performing age groups (typically those in the middle range of age categories) and those in the older age groups, the current data suggest that this gap has narrowed (Appendix Table 7-8). For example, in 1992, 35- to 44-year-olds answered 65% of the trend questions correctly, whereas those 65 years or older answered 47% of the questions correctly. By 2016, the top-performing age group (25- to 34-year-olds) answered 67% of the questions correctly, while respondents age 65 years or older answered 55% correctly. The gap thus shrank from 18 percentage points to 12 percentage points between 1992 and 2016. Analyses of surveys conducted between 1979 and 2006 concluded that public understanding of science has increased over time and by generation, even after controlling for formal education levels (Losh 2010, 2012).

Factual knowledge about science, as measured in the current GSS, is also associated with respondents' sex. Men (67%) tend to answer somewhat more factual science knowledge questions in the GSS correctly than women (60%) (Figure 7-8). The Pew Research Center found a similar result using a set of 12 questions that were different from those used by the NSF survey (Funk and Goo 2015). In the Pew survey, men's scores averaged 8.6, whereas women's scores averaged 7.3. For the NSF S&T survey (i.e., the current GSS data), men have typically done slightly better on physical science questions, whereas women have performed more similarly to men on biology questions (Appendix Table 7-10). However, men did better than women on an expanded set of biology questions in the 2008 GSS, which suggests that sex differences in correct answers may depend on the specific questions asked. The 2015 Pew Research Center data focus primarily on physical science questions, and the organization has not consistently seen these types of gender differences for questions focused on health and biomedical knowledge (Funk and Goo 2015). Some evidence also suggests that men might be more likely to guess rather than say they do not know the correct answer. This could partly account for men's slightly higher science knowledge score (Mondak 2004). Pew did not differentiate biology from physics questions.

FIGURE 7-8

Correct answers to trend factual knowledge of science scale, by respondent characteristic: 2016



Note(s)

Data reflect average percentage of nine questions answered correctly. "Don’t know" responses and refusals to respond counted as incorrect. See Appendix Table 7-2 for explanation, list of questions, and additional respondent characteristics. See Appendix Tables 7-9 and 7-10 for responses to individual questions.

Source(s)

NORC at the University of Chicago, General Social Survey (2016).

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Evolution and the Big Bang

The GSS includes two additional true-or-false science questions that are not included in the index calculation because Americans' responses appear to reflect factors beyond familiarity with scientific facts. One of these questions is about evolution, and the other is about the origins of the universe. In 2016, 52% of Americans correctly indicated that "human beings, as we know them today, developed from earlier species of animals," and 39% correctly indicated that "the universe began with a big explosion" (Appendix Table 7-10). Both scores are relatively low compared with scores on the other knowledge questions in the survey. The percentage of Americans answering the evolution question has risen from a low of 42% in 2004, while the origins of the universe question is similar to where it has been since 2010 (38%) but is higher than it was during much of the last two decades—it was at lows of 32% in 1990 and 1997 (Appendix Table 7-9).

Those with more education and more factual knowledge typically do well on the two questions. Younger respondents are also more likely to answer both questions correctly. For example, 70% of those ages 18–24 years answered the evolution question correctly, whereas 45% of those 65 or older answered the evolution question correctly. This pattern is not as pronounced for the other knowledge questions described above (Appendix Table 7-10).

An additional question-wording experiment was included in the 2016 GSS to expand on similar experiments conducted in 2004 (NSB 2006) and 2012 (NSB 2014, 2016). These experiments involve randomly giving each survey respondent one of two or three different survey questions and then comparing the results. The earlier experiments showed that changing the wording to the evolution and origin of the universe questions substantially increased the percentage of respondents getting them correct. For example, in 2012, 48% of those asked whether it was true or false that "human beings, as we know them today, developed from earlier species of animals" gave the correct answer of true, but 72% answered the question correctly when presented with the same statement with the addition of the preface "According to the theory of evolution." Similarly, 39% of respondents correctly stated it was true that "the universe began with a big explosion," but 60% gave the correct answer when presented with the same statement prefaced by "According to astronomers" (Appendix Table 7-9).

Similar patterns were evident in the 2016 version of the experiments. For evolution, 74% gave the correct response to the evolution question when respondents were asked whether it was true or false that "elephants, as we know them today, descended from earlier species of animals" (for a discussion of this question, see [Maitland, Tourangeau, and Yan 2014] and [Maitland, Tourangeau, Yan, Bell, et al. 2014]). This is 22 percentage points higher than the 52% who gave the correct answer when asked the similar question about humans. For the Big Bang question, 69% gave the correct response when the preface "According to astronomers" was added to the original question, and 64% gave the correct response when asked whether it was true or false that "the universe has been expanding ever since it began." These represent differences of 30 percentage points and 25 percentage points, respectively, from the 39% of respondents who gave the correct response when asked the original question of whether the universe began with a huge explosion. As before, the results suggest that the evolution and origin of the universe items, as originally worded, may lead some people to provide incorrect responses based on factors other than their knowledge of what most scientists believe. While issues of personal identity are not the focus of *Indicators,* other research has pointed to the important role that religious beliefs play in shaping views about evolution and the origins of the universe (e.g., [Roos 2014]). While issues of personal identity are not the focus of *Indicators,* research has pointed to the role that religious beliefs play in shaping views about evolution and the origins of the universe (e.g., [Roos 2014]). For additional findings related to these questions, see sidebar 💬 Testing Alternative Wording of the Big Bang and Evolution Questions.

SIDEBAR

Testing Alternative Wording of the Big Bang and Evolution Questions

The General Social Survey (GSS) included an experiment to test which alternative question wording regarding the origin of the universe (the "Big Bang") and evolution best captures overall knowledge of science. These questions were part of the NSF's factual knowledge of science questions until, as noted above, it was found that small question wording changes substantially improve the number of correct answers.

Asking respondents about what scientists believe, rather than implicitly what the respondent believes, increases correct responding. Asking about the evolution of elephants or whether the universe is expanding also increases the number of correct responses. This suggests the possibility that Americans may be answering these questions incorrectly due to personal views rather than a lack of knowledge about what science considers the correct answers. If so, alternative questions might be selected that could better capture factual knowledge of science.

It is important, however, to ensure that any proposed alternative questions capture factual knowledge of science better than the existing questions. The fact that people give more correct answers to a reworded question need not indicate that the reworded question better captures general knowledge. The reworded questions may have cues, such as the mention of scientists, which yield more correct responses because of reasons other than knowledge.

Also, even if people know the correct answer to the human evolution question but select the wrong answer because of personal beliefs, those beliefs might indicate a broader lack of understanding of science. For example, a question about the evolution of elephants could more accurately capture knowledge of what science says about evolution but be a worse overall indicator of knowledge of other scientific facts or understanding of the scientific process.

A key test, then, of the value of alternative wordings is whether they are more strongly associated with the current 9-item factual knowledge of science questions than the original questions. If they are, this suggests that the questions likely capture broad factual knowledge of science better. Another, less critical indicator includes the questions' association with understanding the scientific process.

An examination of all GSS data to date containing the various question wordings finds that those questions prefaced with "According to astronomers…" or "According to the theory of evolution…" do better than the alternative questions with respect to factual knowledge of science. That is, the "According to" questions have a stronger association with factual knowledge than do the alternatives. In particular, people correctly answering either of the "According to" questions have a factual knowledge score on average about 1.7 points higher on the 9-point scale than those who answer these questions incorrectly. This contrasts with a 1.3-point difference for those correctly versus those incorrectly answering the original Big Bang question and a 1-point difference for the "universe is expanding" question. The 1.7-point difference on the "According to" evolution question also contrasts with a 1.1-point difference for the original evolution question and a 1-point difference for the elephant evolution question.

The "According to" Big Bang question also has a stronger association with understanding of the scientific process than the original Big Bang question. The "According to" Big Bang question does not have a demonstrably stronger relationship with understanding of the scientific process than *the universe is expanding* alternative. Similarly, it is not clear which of the three versions of the evolution question has a stronger relationship with understanding of the scientific process. The findings for understanding the scientific process are less definitive in part because such understanding has a generally weaker relationship with the question alternatives than does the factual knowledge score and because relatively little data are available for the alternatives.

The stronger relationship of the “According to” questions with factual knowledge of science than the original or other alternative questions suggests that these “According to” questions are better indicators of such knowledge. Also, the stronger relationship of the “According to” Big Bang question with knowledge of the scientific process provides additional evidence for this question over the original version of the question. Whether the “According to” questions should replace the original questions will depend in part on weighing their strengths against losing the long-time series available for the original questions.

SIDEBAR

Race, Ethnicity, and Factual Science Knowledge

A recent National Academies (NASEM 2016c) report on science literacy highlighted racial disparities in science knowledge as a topic in which scholars have done too little research. The report noted that studies done by the Pew Research Center highlighted consistent differences in knowledge scores using Pew's set of 12 questions (Funk and Goo 2015) but concluded that more research is needed to understand the factors that may be contributing to racial disparities in science knowledge.

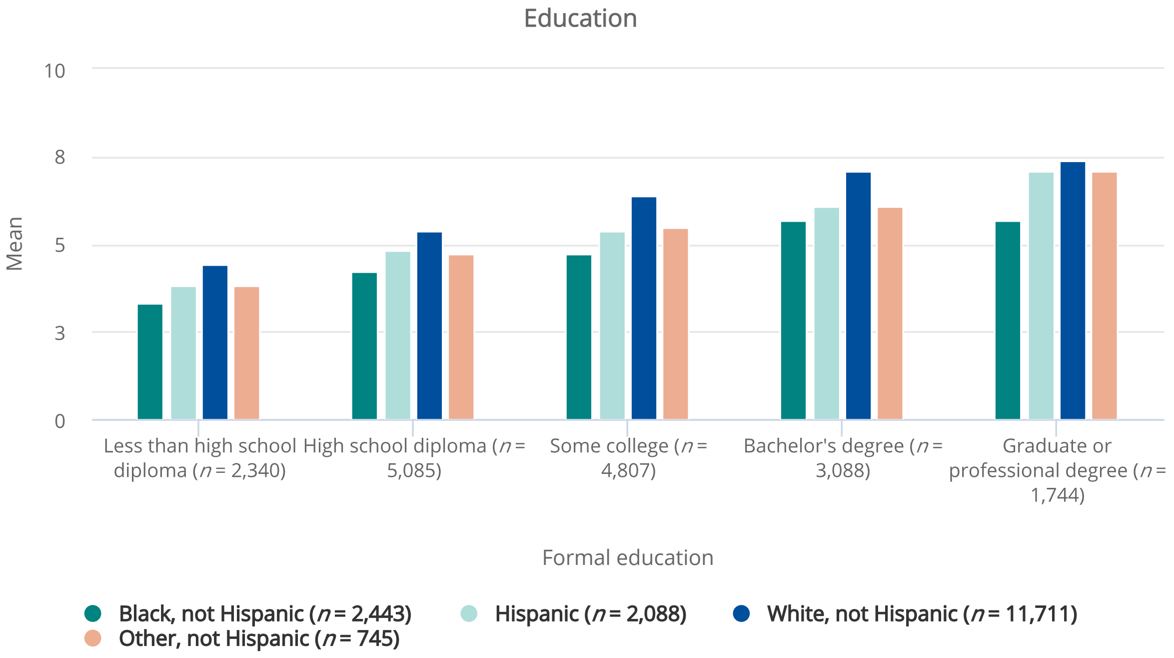
The biennial NSF S&T survey, which is a major data source for this chapter, typically has insufficient sample size to analyze knowledge scores by race and ethnicity. However, when data from the 2006–16 S&T surveys are combined, patterns similar to those reported by Pew emerge. White respondents not of Hispanic origin for whom a high school education was their highest degree, on average, answered 5.4 of the 9 factual knowledge questions correctly; their black counterparts answered an average of 4.2 of the questions correctly. This is a 1.2-point gap. White respondents whose highest education was a bachelor's degree answered an average of 7.1 questions correctly, whereas black respondents with the same overall education level answered 5.7 questions correctly. This remains a similar 1.4-point gap. The same pattern was evident when comparing white and Hispanic respondents (📊 Figure 7-A).

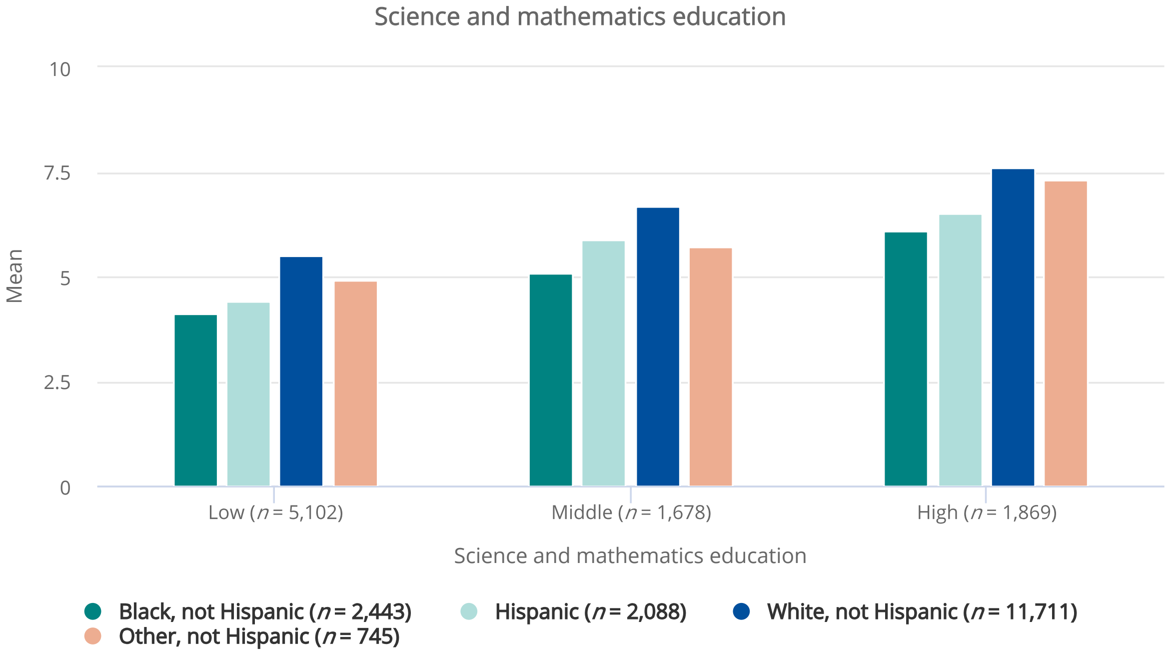
Looking at the number of science and mathematics courses taken in high school and college reveals a similar pattern. Among those who took relatively few science and mathematics courses (those who were in the bottom third of all respondents for the number of such course taken), white respondents answered an average of 5.5 science knowledge questions correctly, and black respondents answered 4.1 questions correctly. This represents a 1.4-point gap. The corresponding gap between white and black respondents was 1.5 points among those who took relatively more science and mathematics courses (those who were in the top third of all respondents). The patterns are again similar when comparing white and Hispanic respondents (📊 Figure 7-A).

As suggested by the National Academies report (NASEM 2016c), fully understanding why differences in science knowledge scores vary will require additional research. There may be systematic differences, for example, in the quality of the education that different groups are receiving. Also, alternative types of science knowledge questions might result in a different pattern. Another line of research could examine how these differences might affect how different groups think about science both in terms of their willingness to choose scientific careers or their support and appreciation for science.

FIGURE 7-A

Correct answers to factual knowledge questions, by respondent characteristic: 2006–16 (combined)





Note(s)

See notes to Appendix Table 7-2 for an explanation of the trend factual knowledge of science scale. Categories do not add to total *n* because "don't know" responses and refusals to respond are not shown. For science and mathematics education, "low" equates to five or fewer high school and college science or mathematics courses, "middle" is six through eight courses, and "high" means nine or more courses. "Don't know" responses and refusals to respond count as incorrect. Hispanic includes respondents of any race who identify as Hispanic. Other includes American Indian or Alaska Native, Asian Indian, Chinese, Filipino, Japanese, Korean, Vietnamese, Other Asian, Native Hawaiian, Guamanian or Chamorro, Samoan, Other Pacific Islander, and some other race.

Source(s)

NORC at the University of Chicago, General Social Survey (2006–16).

Science and Engineering Indicators 2018

International Comparisons

There are very few current international efforts to measure science knowledge in the way that this is done in the United States because scholarly attention has shifted to understanding attitudes about science and scientists. This has likely occurred because of the aforementioned evidence that science knowledge is only weakly related to science attitudes (Bauer, Allum, and Miller 2007), including support of science (NASEM 2016c). Most data now available are thus somewhat dated.

Knowledge scores for individual items vary from country to country, and it is rare for one country to consistently outperform others across all items in a given year (▦ Table 7-1). One exception is a 2013 Canadian survey that has Canadians scoring as well as or better than Americans and residents of most other countries on the core science questions (CCA 2014). For the physical and biological science questions, knowledge scores are relatively low in China, Russia, and Malaysia (CRISP 2016; Gokhberg and Shuvalova 2004; MASTIC 2010). Compared with overall scores in the United States and the European Union (EU) (European Commission 2005), scores in Japan (NISTEP 2012) are also relatively low for several questions.

Scores on a smaller set of four questions administered in 12 European countries in 1992 and 2005 show each country performing better in 2005 (European Commission 2005), in contrast to a flat trend in corresponding U.S. data. In Europe, as in the United States, men, younger adults, and more educated people tended to score higher on these questions.

TABLE 7-1

Percentage of correct answers to factual knowledge questions in physical and biological sciences, by region or country: Most recent year

(Percent)

Question	United States[a] (2016)	Canada (2013)	China (2015)	EU (2005)	India (2004)	Israel (2016)	Japan[b] (2011)	Malaysia (2014)	Russia (2003)	South Korea (2004)	Switzerland (2016)
Physical science											
The center of the Earth is very hot. (True)	85	93	47	86	57	86	84	75	NA	87	NA
The continents have been moving their location for millions of years and will continue to move. (True)	81	91	51	87	32	86	89	62	40	87	80
Does the Earth go around the Sun, or does the Sun go around the Earth? (Earth around Sun)	73	87	NA	66	70	86	NA	85	NA	86	NA
All radioactivity is man-made. (False)	70	72	41	59	NA	76	64	20	35	48	NA
Electrons are smaller than atoms. (True)	48	58	22	46	30	60	28	35	44	46	39
Lasers work by focusing sound waves. (False)	45	53	19	47	NA	67	26	30	24	31	NA
The universe began with a huge explosion.[c] (True)	39	68	NA	NA	34	64	NA	NA	35	67	NA
Biological science											

Question	United States[a] (2016)	Canada (2013)	China (2015)	EU (2005)	India (2004)	Israel (2016)	Japan[b] (2011)	Malaysia (2014)	Russia (2003)	South Korea (2004)	Switzerland (2016)
It is the father's gene that decides whether the baby is a boy or a girl.[d] (True)	59	NA	49	64	38	72	26	45	22	59	60
Antibiotics kill viruses as well as bacteria.[e] (False)	51	53	24	46	39	53	28	16	18	30	56
Human beings, as we know them today, developed from earlier species of animals.[f] (True)	52	74	68	70	56	63	78	NA	44	64	NA

NA = not available; question not asked.

EU = European Union.

[a] See Appendix Table 7-9 for U.S. trends.

[b] Numbers for Japan are the average from two studies conducted in 2011.

[c] An experiment in the 2012 General Social Survey showed that adding the preface "according to astronomers" increased the percentage correct from 39% to 60%.

[d] China, EU, and Switzerland surveys asked about "mother's gene" instead of "father's gene." Israel surveys asked about "hereditary material from the father."

[e] Japan survey asked about "antibodies" instead of "antibiotics."

[f] An experiment in the 2012 General Social Survey showed that adding the preface "according to the theory of evolution" increased the percentage answering correctly from 48% to 72%.

Note(s)

See notes to Table 7-2 for the full list of questions in the trend factual knowledge of science scale. EU data include Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, and the United Kingdom but do not include Bulgaria and Romania.

Source(s)

United States—University of Chicago, National Opinion Research Center, General Social Survey (2016), National Science Board (NSB), *Science and Engineering Indicators 2014* (2014), http://www.nsf.gov/statistics/seind14; Canada—Council of Canadian Academies, Expert Panel on the State of Canada's Science Culture, *Science Culture: Where Canada Stands* (2014); China—Chinese Association for Science and Technology/China Research Institute for Science Popularization, Chinese National Survey of Public Scientific Literacy (2015); EU—European Commission, Eurobarometer 224/Wave 63.1: *Europeans, Science and Technology* (2005); India—National Council of Applied Economic Research, National Science Survey (2004); Israel—Israeli Ministry of Science, Technology and Space, Geocartography Knowledge Group, Perceptions and Attitudes of the Israeli Public about Science, Technology and Space (2016); Japan—National Institute of Science and Technology Policy/Ministry of Education, Culture, Sports, Science and Technology, Survey of Public Attitudes Toward and Understanding of Science and Technology in Japan (2011); Malaysia—Malaysian Science and Technology Information Centre/Ministry of Science, Technology and Innovation, Survey of the Public's Awareness of Science and Technology: Malaysia (2014); Russia—Gokhberg L, Shuvalova O, *Russian Public Opinion of the Knowledge Economy: Science, Innovation, Information Technology and Education as Drivers of Economic Growth and Quality of Life*, British Council, Russia (2004), Figure 7; South Korea—Korea Science Foundation (now Korea Foundation for the Advancement of Science and Creativity), Survey of Public Attitudes Toward and Understanding of Science and Technology (2004); Switzerland—University of Zurich, Institute of Mass Communication and Media Research, Department of Science, Crisis and Risk Communication, Science Barometer Switzerland (2016).

Science and Engineering Indicators 2018

Reasoning and Understanding the Scientific Process

U.S. Patterns and Trends

Another indicator of the public understanding of science focuses on the public's understanding of how science generates and assesses evidence rather than knowledge of particular science facts. Such measures reflect recognition that knowledge of specific S&T facts is conceptually different from knowledge about the overall scientific processes (Miller 1998), as well as the increased emphasis placed on process in science education (NRC 2012).

Data on three scientific process elements—probability, experimental design, and the scientific method—show trends in Americans' understanding of the process of scientific inquiry. One set of questions tests how well respondents apply the principles of probabilistic reasoning to a set of questions about a couple whose children have a 1-in-4 chance of suffering from an inherited disease. A second set of questions deals with the logic of experimental design, asking respondents about the best way to design a test of a new drug for high blood pressure. A third open-ended question probes what respondents think it means to study something scientifically. Because probability, experimental design, and the scientific method are all central to scientific research, these questions are relevant to how respondents evaluate scientific evidence. These measures are reviewed separately and then as a combined indicator of public understanding about scientific inquiry.

With regard to probability, 82% of Americans in 2016 correctly indicated that the fact that a couple's first child has the illness has no relationship to whether three future children will have the illness. In addition, about 72% of Americans correctly responded that the odds of a genetic illness are equal for all of a couple's children. Overall, 64% got both probability questions correct (Table 7-2; Appendix Table 7-11). The public's understanding of probability has been fairly stable over time, with the percentage giving both correct responses ranging from 64% to 69% since 1999 and has been no lower than 62% dating back to 1992 (Table 7-2).[2]

With regard to understanding experiments, about half (51%) of Americans were able to answer a question about how to test a drug and then provide a correct response to an open-ended question that required them to explain the rationale for an experimental design (i.e., giving 500 people a drug while not giving the drug to 500 additional people, who then serve as a control group) (Table 7-2). The 2016 results, similar to the 2014 results and results from most recent survey years, are a substantial improvement over the unusually low 2012 results that had only 34% answering this set of questions correctly. Although there has been an average increase in the percentage of correct responses over the previous two decades, there has also been substantial year-to-year variation that may in part reflect reliance on human coders to categorize responses.[3]

When all the scientific reasoning questions are combined into an overall measure of understanding of scientific inquiry (Figure 7-9), about 43% of Americans could both correctly respond to the two questions about probability and provide a correct response to at least one of the open-ended questions about experimental design or what it means to study something scientifically (Table 7-2). The 2016 proportion was not meaningfully different from the 46% found in 2014. Further, 2014 had the highest proportion of correct responses on surveys for which NSF has data, dating back to 1995. In general, men, respondents with more education, and respondents with higher incomes did better on the scientific inquiry questions. Both younger and older age groups did relatively less well compared with those in the middle of the age range (Appendix Table 7-11).

TABLE 7-2

Correct answers to scientific process questions: Selected years, 1999–2016

(Percent)

Question	1999	2001	2004	2006	2008	2010	2012	2014	2016
Understanding of scientific inquiry scale[a]	32	40	39	41	36	42	33	46	43
Components of understanding scientific inquiry scale									
Understanding of probability[b]	64	67	64	69	64	66	65	66	64
Understanding of experiment[c]	34	40	46	42	38	51	34	53	51
Understanding of scientific study[d]	21	26	23	25	23	18	20	26	23

[a] To be classified as understanding scientific inquiry, the survey respondent had to (1) answer correctly the two probability questions stated in footnote b, and (2) either provide a theory-testing response to the open-ended question about what it means to study something scientifically (see footnote d) or a correct response to the open-ended question about experiment (i.e., explain why it is better to test a drug using a control group [see footnote c]).

[b] To be classified as understanding probability, the survey respondent had to answer correctly *A doctor tells a couple that their genetic makeup means that they've got one in four chances of having a child with an inherited illness.* (1) *Does this mean that if their first child has the illness, the next three will not have the illness?* (No); and (2) *Does this mean that each of the couple's children will have the same risk of suffering from the illness?* (Yes).

[c] To be classified as understanding experiment, the survey respondent had to answer correctly (1) *Two scientists want to know if a certain drug is effective against high blood pressure. The first scientist wants to give the drug to 1,000 people with high blood pressure and see how many of them experience lower blood pressure levels. The second scientist wants to give the drug to 500 people with high blood pressure and not give the drug to another 500 people with high blood pressure, and see how many in both groups experience lower blood pressure levels. Which is the better way to test this drug?* and (2) *Why is it better to test the drug this way?* (The second way because a control group is used for comparison.)

[d] To be classified as understanding scientific study, the survey respondent had to answer correctly (1) *When you read news stories, you see certain sets of words and terms. We are interested in how many people recognize certain kinds of terms. First, some articles refer to the results of a scientific study. When you read or hear the term scientific study, do you have a clear understanding of what it means, a general sense of what it means, or little understanding of what it means?* and (2) (If "clear understanding" or "general sense" response) *In your own words, could you tell me what it means to study something scientifically?* (Formulation of theories/test hypothesis, experiments/control group, or rigorous/systematic comparison.)

Note(s)

Data reflect the percentage of survey respondents who gave a correct response to each concept. "Don't know" responses and refusals to respond are counted as incorrect and are not shown. See Appendix Table 7-11 for more detail on the probability questions.

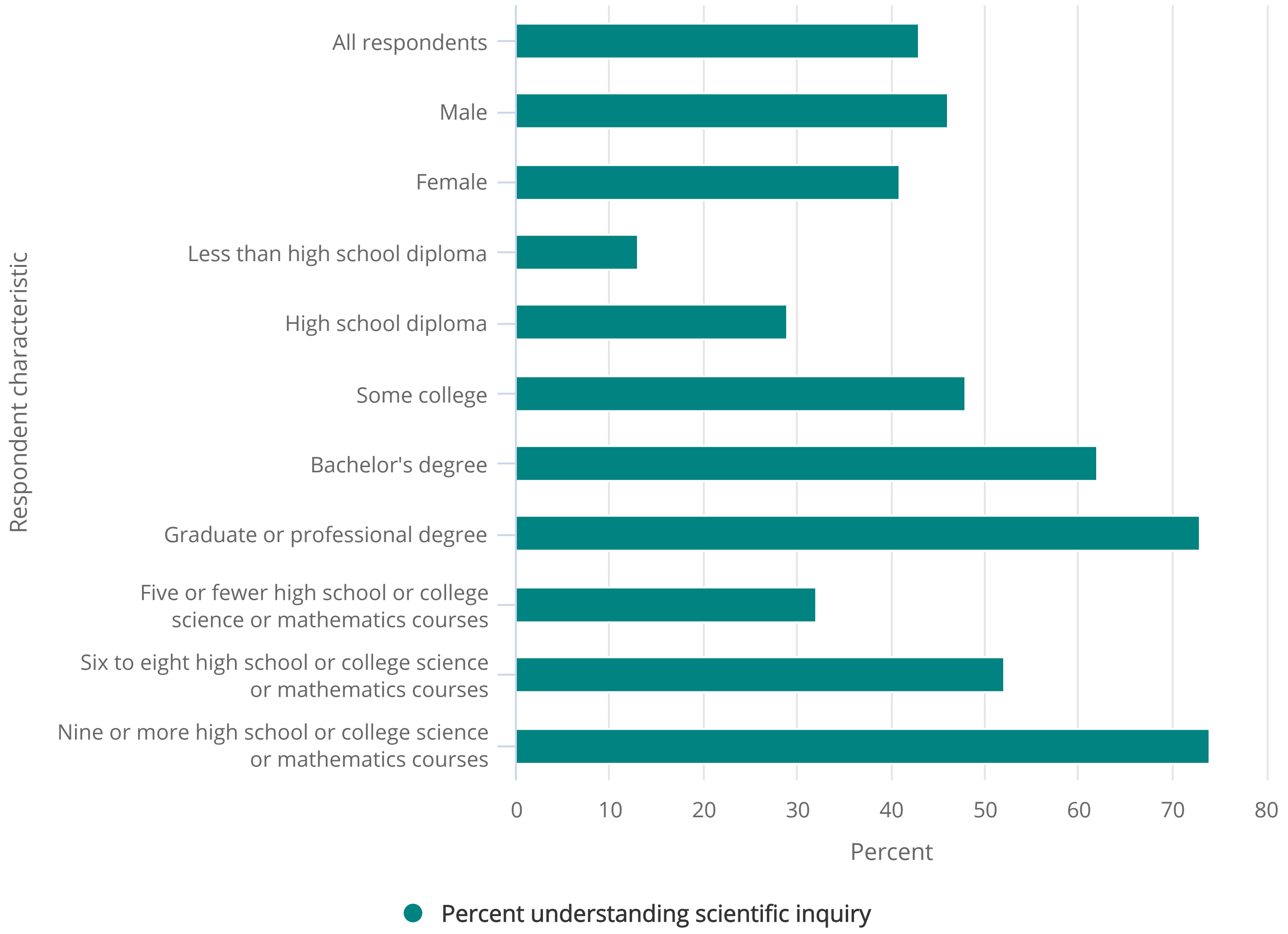
Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Survey of Public Attitudes Toward and Understanding of Science and Technology (1999, 2001); University of Michigan, Survey of Consumer Attitudes (2004); NORC at the University of Chicago, General Social Survey (2006–16).

Science and Engineering Indicators 2018

FIGURE 7-9

Understanding scientific inquiry, by respondent characteristic: 2016



Note(s)

See Appendix Table 7-11 for explanation of understanding scientific inquiry and questions included in the index and additional respondent characteristics.

Source(s)

NORC at the University of Chicago, General Social Survey (2016).

Science and Engineering Indicators 2018

International Comparisons

Reasoning and understanding have not been the focus of surveys in most other countries in recent years. A 2010 Chinese survey reported that 49% understood the idea of probability, 20% understood the need for comparisons in research, and 31% understood the idea of scientific research (CRISP 2010). In a July 2011 Japanese survey, 62% correctly answered a multiple-choice question on experiments related to the use of a control group, whereas 57% answered correctly in a follow-up December 2011 survey (NISTEP 2012). As noted previously, 66% of Americans provided a correct response to a similar question in 2014.

Pseudoscience

Another indicator of public understanding about S&T comes from a measure focused on the public's capacity to distinguish science from pseudoscience. One such measure, Americans' views on whether astrology is scientific, has been included in *Indicators* because of the availability of data going back to the late 1970s. Other examples of pseudoscience include the belief in lucky numbers, extrasensory perception, or magnetic therapy.[4]

More Americans see astrology as unscientific today than in the past, although there has been some variation in recent years. In 2016, about 60% of Americans said astrology is "not at all scientific," a value near the middle of the historical range and down somewhat from 65% in 2014. Twenty-nine percent said they thought astrology was "sort of scientific," and the remainder said they thought astrology was "very scientific" (8%) or that they "didn't know how scientific" astrology is (3%). The percentage of Americans who report seeing astrology as unscientific has ranged between 50% (1979) and 66% (2004).

Respondents with more years of formal education and higher income were less likely to see astrology as scientific. For example, in 2016, 76% of those with bachelor's degrees indicated that astrology is "not at all scientific," compared with 57% of those whose highest level of education was high school. Age was also related to perceptions of astrology. Younger respondents were the least likely to reject astrology, with only 54% of the youngest age group (18–24 years old) and 53% of the next group (25–34 years old) saying that astrology is "not at all scientific." At least 60% of all other groups rejected astrology (Appendix Table 7-12).

Perceived Understanding of Scientific Research

U.S. Patterns and Trends

While factual knowledge is important, people may also develop attitudes and engage in behaviors because of their perception of how much they know (Ladwig et al. 2012). The NSF survey has included data on the degree to which respondents believe they "have a clear understanding of what it means" when they "read or hear the term scientific study." In 2016, 31% of Americans said they thought they had a clear understanding of the meaning, while 48% said they felt they had a "general understanding" of the topic. Another 21% said they had "little understanding" (19%) or said they did not know (2%) (Appendix Table 7-13 and Appendix Table 7-14).

The proportion of respondents saying they have a clear understanding of what the term *scientific study* means was 22% in 1979 and climbed to a high of 37% in 1997 before dropping back down to 24% in 2012 (Appendix Table 7-14). The current level, 31%, is at the overall average (31%); men, those with more education, and those with more income are most likely to say they have a clear understanding. A perceived sense of "clear understanding" also appears to peak in the 25- to 34-year-old age group. Factual knowledge also matters. About 51% of those in the highest quartile of factual knowledge as measured by the NSF said they had a clear understanding of the term *scientific study*. About 15% of those in the lowest quartile of factual knowledge said they felt they had a clear understanding of the term. About 4% of those in the highest knowledge quartile and 44% of those in the lowest knowledge quartile said they had "little understanding" of the term (Appendix Table 7-13).

International Comparisons

Only a small number of countries ask about their residents' perceived understanding of science. In Switzerland, about 28% agreed with a statement about being well-informed about science and research by choosing 4 or 5 on a 5-point scale, where 1 indicated complete disapproval of the statement and 5 indicated complete approval (Schafer and Metag 2016). This is similar to the 31% who expressed "clear understanding" in the United States.

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[1] Survey items that test factual knowledge sometimes use easily comprehensible language at the cost of scientific precision. This may prompt some highly knowledgeable respondents to believe that the items blur or neglect important distinctions and, in a few cases, may lead respondents to answer questions incorrectly. In addition, the items do not reflect the ways that established scientific knowledge evolves as scientists accumulate new evidence. Although the text of the factual knowledge questions may suggest a fixed body of knowledge, it is more accurate to see scientists as making continual, and often subtle, modifications in how they understand existing data in light of new evidence.

[2] Earlier NSF surveys used for the *Indicators* report employed additional questions to measure understanding of probability. Bann and Schwerin (2004) identified a smaller number of questions that could be administered to develop a comparable indicator. Starting in 2004, the NSF surveys used these questions for the trend factual knowledge scale. This scale does not include the questions aimed at studying scientific reasoning and understanding (e.g., questions about probability or the design of an experiment).

[3] Declines such as those seen in 2012 need to be regarded with caution. In that case, the percentage of Americans who correctly answered the initial multiple-choice question about how to conduct a pharmaceutical trial stayed stable between 2010 and 2012. It was only the follow-up question that asked respondents to use their own words to justify the use of a control group that saw a decline. For this question, interviewers record the response, and then trained coders use a standard set of rules to judge whether the response is correct. Although the instructions and training have remained the same in different years, small changes in survey administration practices can sometimes substantially affect such estimates.

[4] Because astrology is based on systematic observation of planets and stars, respondents might believe that this makes it "sort of scientific." The fact that those with more formal education and higher factual science knowledge scores are consistently more likely to fully reject astrology suggests that this nuance has only a limited effect on results. Another problem is that some respondents may also confuse astrology with astronomy, and such confusion seems most likely to occur in some of the same groups (i.e., relatively lower education and factual knowledge) that might be predicted to get the question wrong. This could artificially inflate the number of wrong responses. However, the question comes immediately after a question that asks respondents whether they ever "read a horoscope or personal astrology report," which offers respondents a hint that astrology is not astronomy. Also noteworthy is the fact that a Pew Forum on Religion & Public Life study (2009) using a different question found that 25% of Americans believe in "astrology, or that the position of the stars and planets can affect people's lives." Gallup found the same result with the same question in 2005 (Lyons 2005). In contrast, similar to 2014, the 2010 GSS found that 6% saw astrology as "very scientific," and 28% said they saw astrology as "sort of scientific" (34% total). The Pew Research Center found that 73% could distinguish between astrology and astronomy and that there were few demographic differences, beyond education (Funk and Goo 2015).

Public Attitudes about S&T in General

Scientific interest and knowledge are only aspects of how people think about S&T. How people perceive science and scientists can also matter considerably. Such attitudes could influence the public's willingness to fund S&T through public investment (Besley forthcoming; Miller, Pardo, and Niwa 1997; Muñoz, Moreno, and Luján 2012), as well as young people's willingness to enter S&T training and choose jobs in S&T (Besley 2015; Losh 2010). Committing resources—whether money to fund science research or time to pursue S&T training—means trusting that such commitments will pay off over the long term for individuals, families, and society. General views about S&T may also help shape opinions about specific technologies and research programs that could enhance lives or pose new risks.

This section presents general indicators of public attitudes and orientations toward S&T in the United States and other countries. It covers information on the perceived promise of and reservations about S&T, overall support for government funding of research, and confidence in scientific community leaders. Overall, the data show that Americans support both S&T and the people involved in S&T.

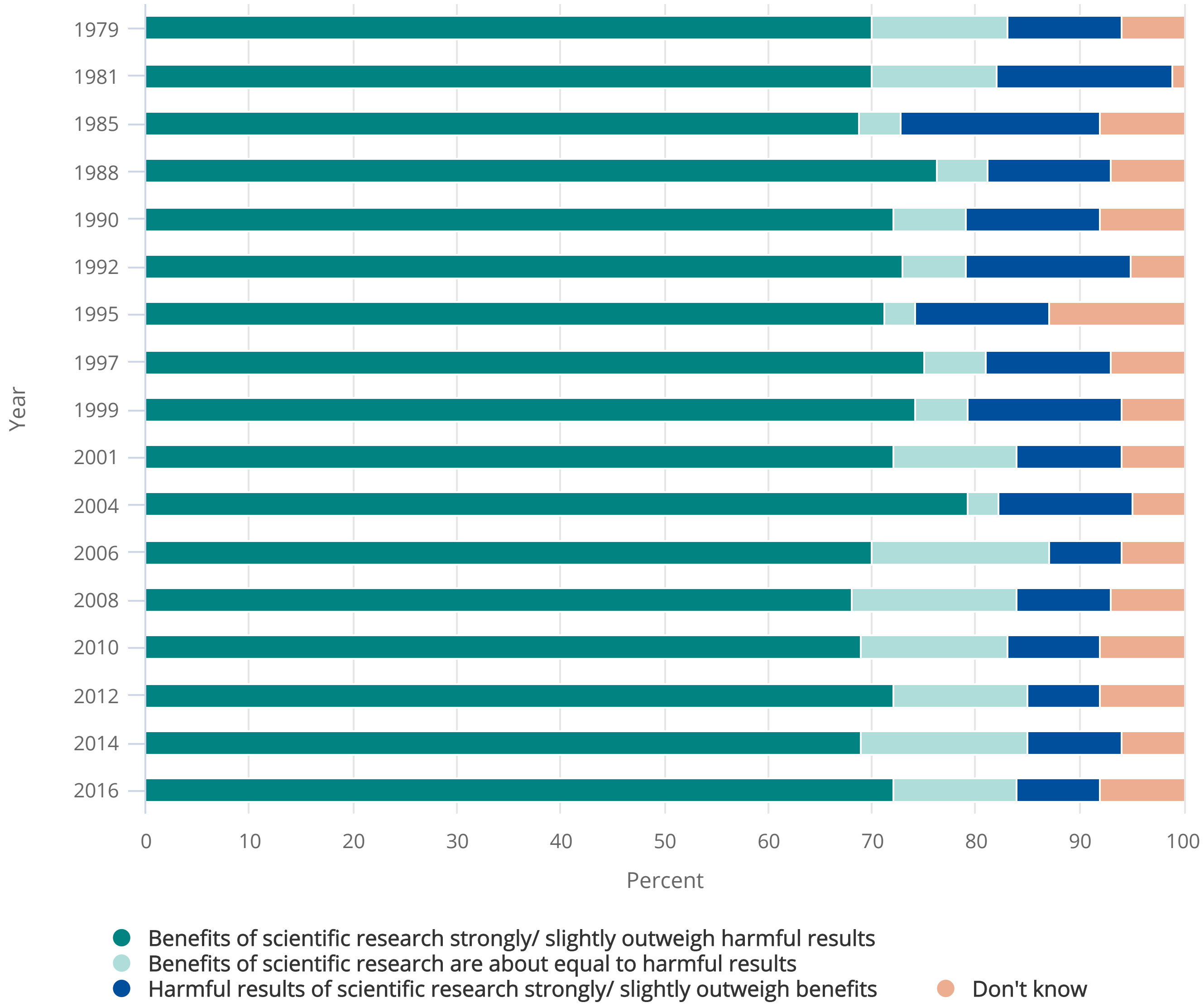
Perceived Promise of and Reservations about S&T

U.S. Patterns and Trends

Overall, Americans remain strong believers in the benefits of S&T even while seeing potential harms. Surveys since at least 1979 show that roughly 7 in 10 Americans have said they believe the effects of scientific research are more positive than negative for society (Figure 7-10; Appendix Table 7-15 and Appendix Table 7-16). In the 2016 GSS, 72% saw more benefits than harms from science, including 45% who said they believed the benefits "strongly outweigh" the negatives and 27% who said the benefits "slightly outweigh" the potential harms. About 8% said science creates more harms than benefits, including 6% who indicated that they thought science caused "slightly" more harm and 2% who thought the balance was "strongly" toward harm.

FIGURE 7-10

Public assessment of scientific research: 1979–2016



Note(s)

Responses to the following: *People have frequently noted that scientific research has produced benefits and harmful results. Would you say that, on balance, the benefits of scientific research have outweighed the harmful results, or have the harmful results of scientific research been greater than its benefits?* In this figure, "Benefits...outweigh harmful results" and "Harmful results...outweigh benefits" each combine responses of "strongly outweigh" and "slightly outweigh." Figure includes all years for which data were collected. Percentages may not add to total because of rounding.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Survey of Public Attitudes Toward and Understanding of Science and Technology (1979–2001); University of Michigan, Survey of Consumer Attitudes (2004); NORC at the University of Chicago, General Social Survey (2006–16). See Appendix Tables 7-15 and 7-16.

Science and Engineering Indicators 2018

Older respondents and those with more education, income, and scientific knowledge are more likely to believe in the benefits of science than others (Appendix Table 7-15). For example, 52% of those who had not completed high school said they believe science does more good than harm, but 84% of those with bachelor's degrees and 94% of those with graduate degrees expressed this view (Appendix Table 7-15).[1]

Americans also overwhelmingly agree that S&T will foster "more opportunities for the next generation." In the 2016 GSS, 91% of Americans "strongly" agreed (39%) or agreed (52%) that S&T will create more opportunities (Appendix Table 7-17). This is up slightly from 2012 and 2014 but consistent with surveys from 2006 through 2010, during which 90%–91% agreed about the relative value of S&T. Overall, belief in opportunity from science has grown from 76% in 1985 (Appendix Table 7-17 and Appendix Table 7-18).

Although Americans are generally positive about science, concern about the speed at which science may be changing "our way of life" remains close to historically high levels. In 2016, about 51% of Americans "strongly" agreed (11%) or agreed (40%) that "science makes our way of life change too fast," percentages similar to those in 2014 (Appendix Table 7-19 and Appendix Table 7-20). Demographic patterns are also similar to those found for the question addressing benefits and harms. Those with less education and less income were more likely to express worry about the pace of change. For example, 59% of those with a high school degree agreed that science was changing life too fast, whereas 41% of those with a graduate degree agreed with this concern. Age, however, was not substantially associated with concerns about the pace of change.

The current high level of concern is similar to that found in 1979, when 53% indicated concern about the pace of change. It is, however, difficult to know if there is an underlying trend because the main increase in concern occurred at the same time (between 2004 and 2008) that the underlying survey switched from a telephone survey to a face-to-face survey. Concern about the pace of change was, nevertheless, lower during much of the 1980s and 1990s.

International Comparisons

Most survey respondents in other countries also generally report strong belief in the value of science, although these beliefs appear to be somewhat higher in the United States. In China, 84% of respondents said in 2015 that they thought S&T would lead to more opportunities for future generations (compared to 91% in the United States for a similar question) (Appendix Table 7-17). About 69% of respondents also said that they thought that "scientific and technological development will create more jobs than [it] will eliminate" (CRISP 2016). In Germany, 10% of respondents agreed that science does more harm than good, and 20% said that science would make life better for future generations. In contrast, 68% said it will lead to both benefits and harms (Wissenschaft im dialog 2016). The responses cannot be directly compared to the United States—where 12% said they believed benefits and harms were about equal (Appendix Table 7-15)—because the equivalent U.S. question does not explicitly give respondents the middle option. Respondents have to volunteer, without prompting, that they see both benefits and harms as equally likely. In Switzerland, 61% of respondents indicated that they generally thought science made life better by selecting 4 or 5 on a 5-point scale, where 1 indicated complete disapproval with a relevant statement and 5 indicated complete approval (Schafer and Metag 2016). Only about a third (34%) also agreed that science makes life move too fast (compared to 51% in the United States). About a third (34%) of Swiss residents also, however, approved of a statement that said the advantages of science and research made it worth the potential damages. In Chile, 39%

of respondents said they thought S&T would bring “many” risks to the world, and another 31% said they thought S&T would bring “some” risks, whereas only 25% said S&T would bring “few risks” or “no risks” (CONICYT 2016).

While not as recent, a 2013 special Eurobarometer on S&T found that, across Europe, large majorities saw substantial benefits from S&T. More than three-quarters (77%) of respondents said they felt that S&T had a “very” (60%) or “fairly” (17%) positive influence on society in their home country (European Commission 2013). Europeans were asked whether they believe S&T would “provide more opportunities for future generations.” Three-quarters of Europeans (75%) agreed. A separate 2013 survey indicated that 74% of Canadians agreed that S&T would create more opportunities (CCA 2014). A third GSS question that was included in the 2013 special Eurobarometer focused on whether respondents agreed or disagreed that “science makes our way of life change too fast,” for which about 62% of Europeans agreed (European Commission 2013). The 2013 Canadian survey suggested that just 35% of Canadians thought science makes life “change too fast” (CCA 2014).

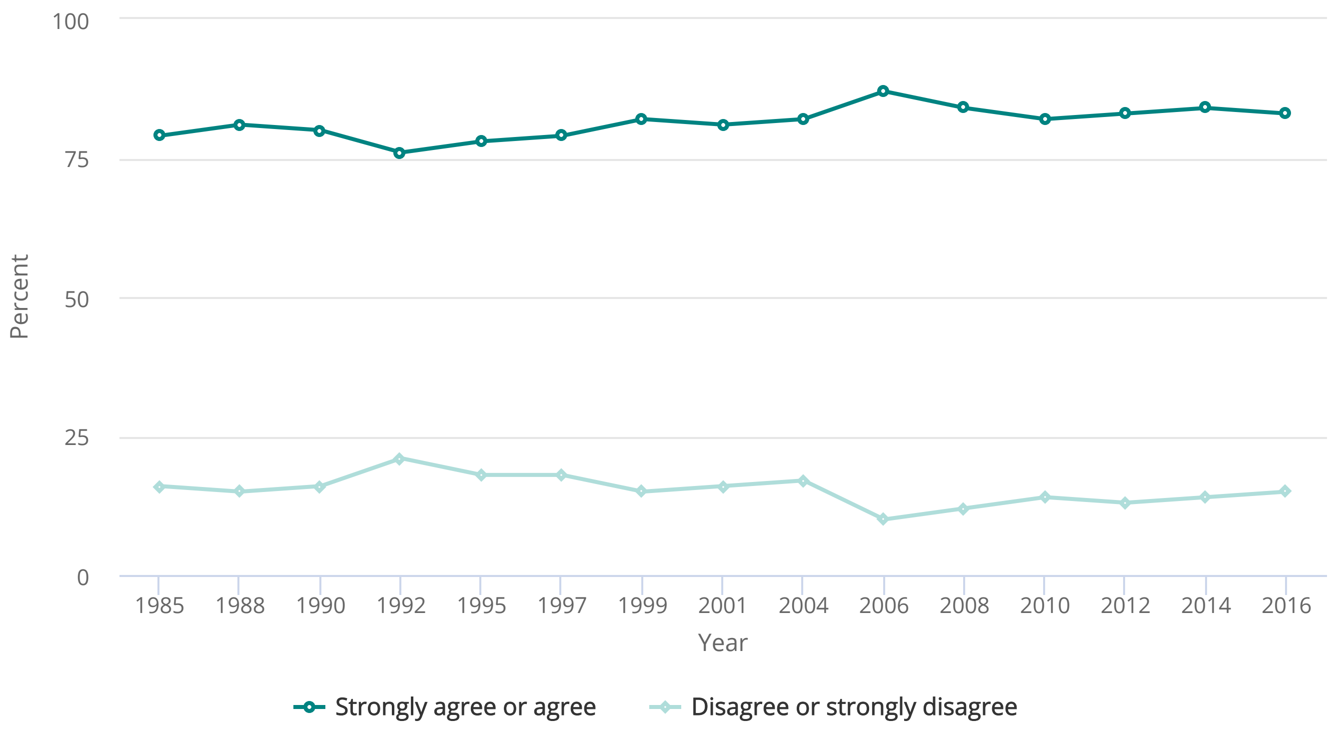
Federal Funding of Scientific Research

U.S. Patterns and Trends

U.S. public opinion has consistently and strongly supported federal spending on scientific research. In the 2016 GSS, 84% of Americans either “strongly agree[d]” (30%) or “agree[d]” (54%) that “even if it brings no immediate benefits, scientific research that advances the frontiers of knowledge is necessary and should be supported by the federal government” (Figure 7-11; Appendix Table 7-21). This is similar to the percentage in recent years, although it has risen from that found in the 1985–2001 NSF surveys, when the value ranged between 77% (1992) and 82% (1999) (Appendix Table 7-22).

FIGURE 7-11

Public opinion on whether government should fund basic scientific research: 1985–2016



Note(s)

Responses to the following: *Even if it brings no immediate benefits, scientific research that advances the frontiers of knowledge is necessary and should be supported by the federal government. Do you strongly agree, agree, disagree, or strongly disagree?* Responses of "don’t know" are not shown.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Survey of Public Attitudes Toward and Understanding of Science and Technology (1985–2001); University of Michigan, Survey of Consumer Attitudes (2004); NORC at the University of Chicago, General Social Survey (2006–16). See Appendix Tables 7-21 and 7-22.

Science and Engineering Indicators 2018

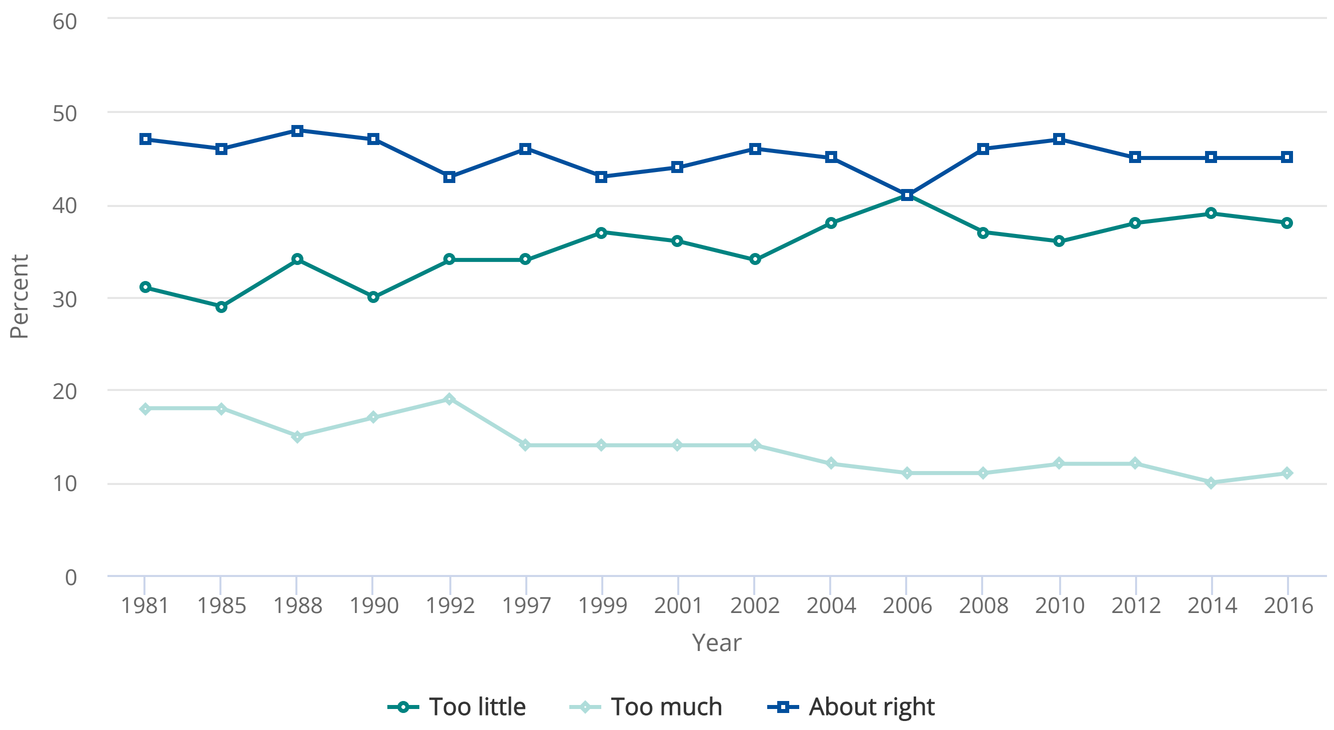
Americans with relatively higher levels of education, more income, and higher scores on the indicators of science knowledge are particularly likely to support funding scientific research. For example, 77% of those for whom high school was their highest level of completed education agreed that funding was needed, but 88% of those with a bachelor’s as their highest degree expressed this view (Appendix Table 7-21).

The Pew Research Center (Funk, Rainie, and Page 2015) also found that, in 2014, most Americans said they think that “government investments” in both basic scientific research (71%) and engineering and technology (72%) “pay off in the long run.” Overall, 61% of Americans told the Pew Research Center that they thought “government investment in research is essential for scientific progress.”

Another indicator of views about S&T is the percentage of Americans who say they "think we're spending too little money" on supporting scientific research and related topics. The 2016 GSS found that 38% of respondents said we are spending "too little" on scientific research, while 45% said the amount was "about right." About 11% said it was "too much" (Figure 7-12; Appendix Table 7-23 and Appendix Table 7-24). In other words, 83% of Americans say they would like to see similar or increased funding for S&T in the years ahead (although the question does not specify who should be responsible for providing this spending). The percentage who said they thought we spend too little on science gradually increased from 1981 to 2006, fluctuating between 29% and 34% in the 1980s, between 30% and 37% in the 1990s, and then varying between 34% and 41% in the 2000s and 2010s. Also, as noted previously, older residents, those with more education, and those with more income were more likely to say that they believe too little is being spent on science.

FIGURE 7-12

Public assessment of amount of spending for scientific research: 1981–2016



Note(s)

Responses to the following: *We are faced with many problems in this country, none of which can be solved easily or inexpensively. I'm going to name some of these problems, and for each one, I'd like you to tell me if you think we're spending too little money on it, about the right amount, or too much: [scientific research].* Responses of "right amount" and "don't know" are not shown.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Survey of Public Attitudes Toward and Understanding of Science and Technology (1981–2001); University of Michigan, Survey of Consumer Attitudes (2004); NORC at the University of Chicago, General Social Survey (2006–16). See Appendix Table 7-23.

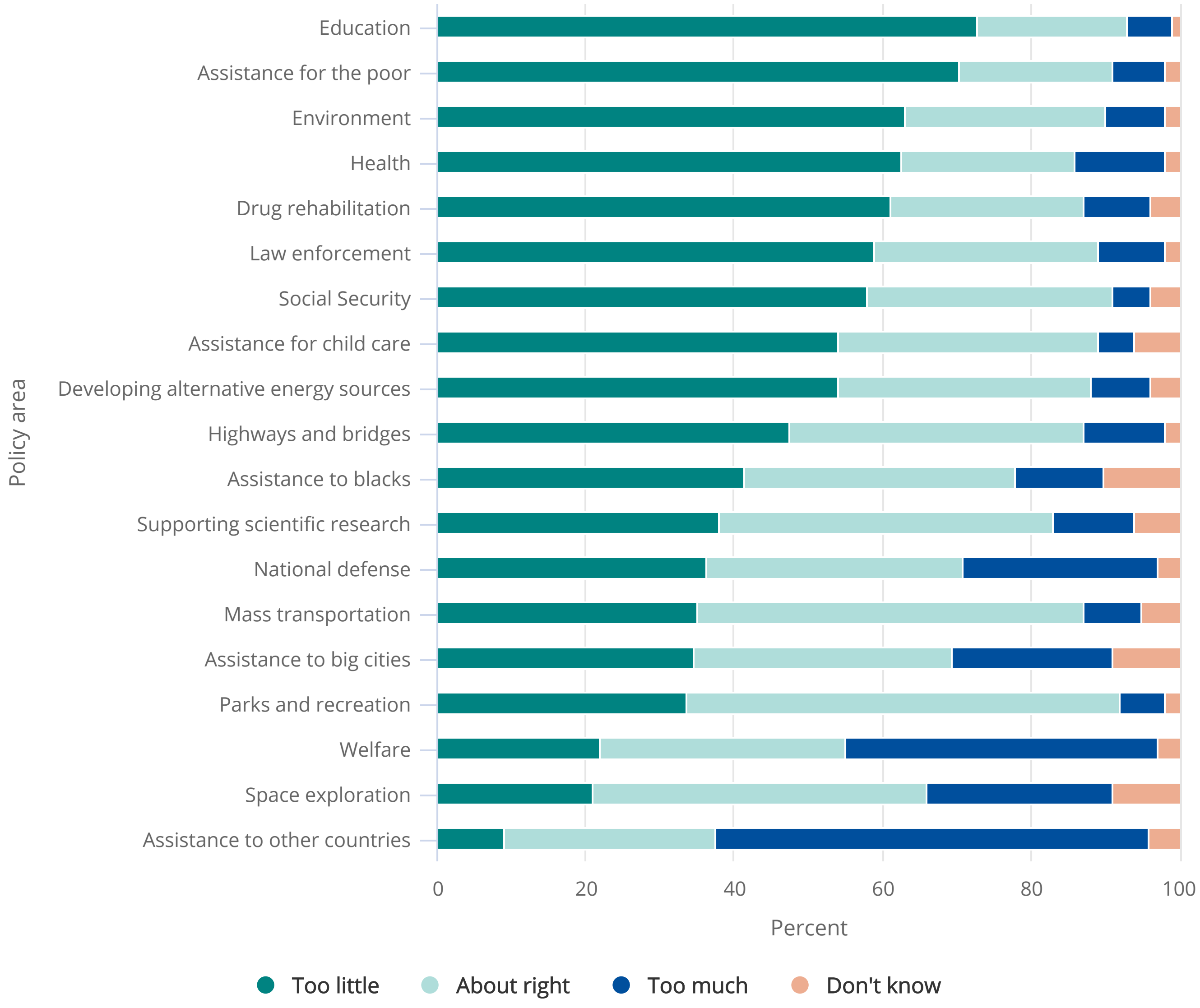
Science and Engineering Indicators 2018

Other S&T domains in which Americans consistently think there is too little spending according to the 2016 GSS include health (62%) (Appendix Table 7-25), improving the environment (63%) (Appendix Table 7-26), and space (21%) (Appendix Table 7-27). Space exploration is one of the areas for which the smallest proportion of Americans see too little spending (Figure 7-13).

Compared with support for spending in other areas, however, support for spending on scientific research may not be especially strong. In the 2016 GSS, Americans were more likely to say several other policy domains need spending more than does S&T (Figure 7-13). Although 38% of Americans say we spend “too little” on scientific research, education has consistently been the domain that Americans are most likely to say receives too little funding, with 72% giving this response in 2016.

FIGURE 7-13

Public attitudes toward spending in various policy areas: 2016



Note(s)

Responses to the following: *We are faced with many problems in this country, none of which can be solved easily or inexpensively. I'm going to name some of these problems, and for each one I'd like you to tell me if you think we're spending too little money on it, about the right amount, or too much.* Percentages may not add to 100% because of rounding.

Source(s)

NORC at the University of Chicago, General Social Survey (2016). See Appendix Table 7-23.

Science and Engineering Indicators 2018

International Comparisons

Respondents in all other countries for which there are data, including both developed and developing countries, also support funding for scientific research. In China, 77% said science should be funded, even if it provides no benefits (compared to 83% for the equivalent question in the United States). In Germany, 49% indicated that, even if the government had to cut spending, it should try to maintain funding for scientific research. Another 45% said research for funding should be cut about the same amount as cuts to other areas (Wissenschaft im dialog 2016). In Switzerland, 73% gave a response of 4 or 5, where 5 indicated “total approval” and 1 indicated “complete disapproval” when presented with a statement about the need to fund science, even without immediate returns. The same proportion (73%) indicated approval for a more general statement that the government should fund scientific research (Schafer and Metag 2016). In Finland, 74% said they believe that investing in science was worthwhile (FSSI 2016). In South America, 91% of Chilean respondents said they agreed that the government should increase funding for scientific research, similar to surveys over the previous decade (CONICYT 2016).

More generally, a broad survey of Europeans found strong support for spending on scientific research in the past. For example, in 2010, 72% of Europeans agreed that scientific research should be supported even in the absence of immediate benefits (European Commission 2010a). A 2013 survey of Canadians similarly found that 76% of respondents said they thought the government should support scientific research (CCA 2014).

Confidence in the Science Community’s Leadership

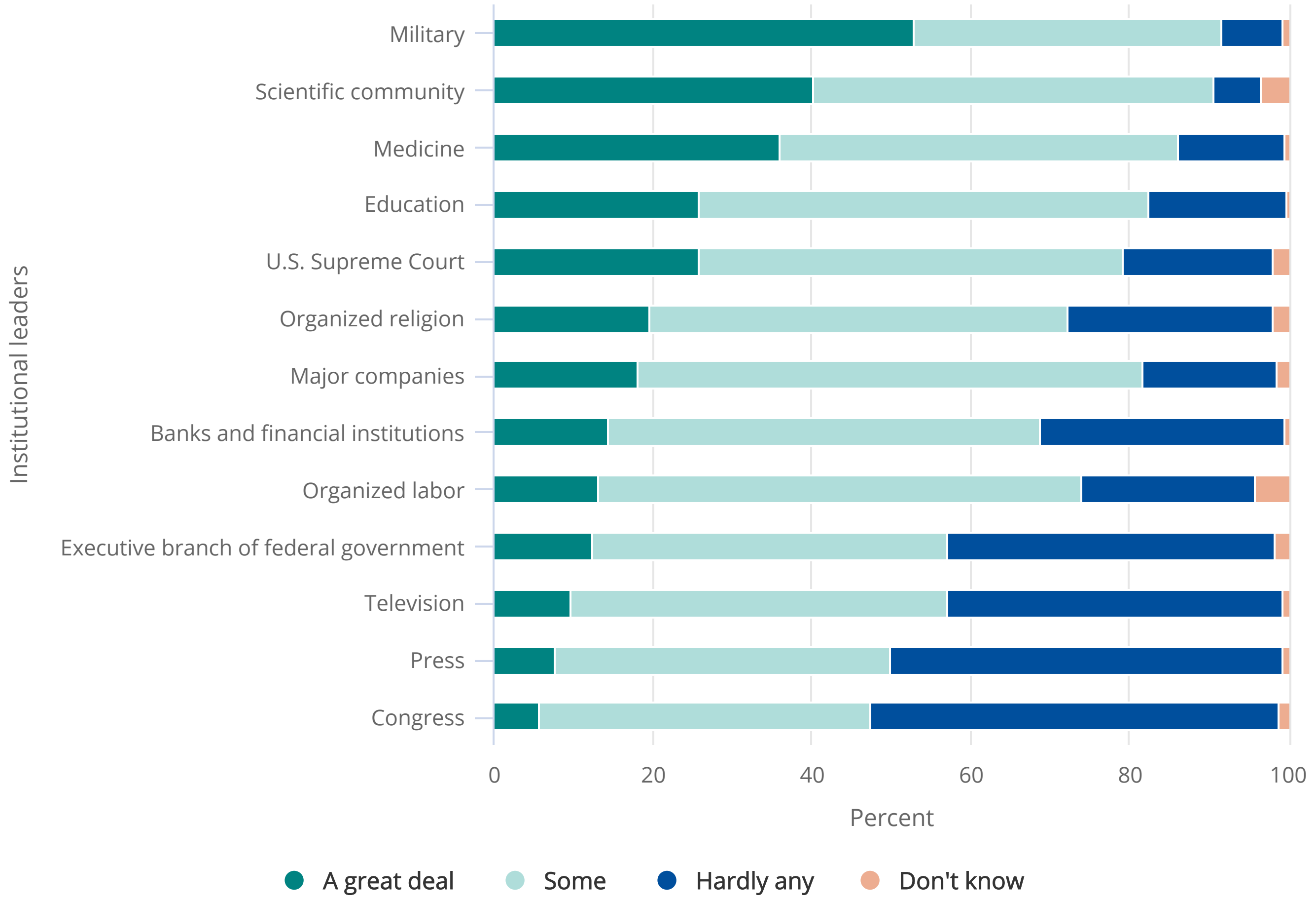
U.S. Patterns and Trends

Few members of the public have the background knowledge or resources to fully evaluate evidence related to scientific questions in the public sphere. People, therefore, often rely on how they perceive decision makers and other cues as decision aids (Fiske and Dupree 2014). The public is also more likely to pay attention to quality information communicated by sources they see as trustworthy in terms of expertise, honesty, and shared identity (Kruglanski and Thompson 1999; Roskos-Ewoldsen, Bichsel, and Hoffman 2002). Public confidence in leaders of the scientific community should therefore increase the likelihood of public acceptance of findings and conclusions based on scientific research, although other factors also matter.

Since 1973, the GSS has tracked public confidence in the leadership of various institutions, including the scientific community. The GSS asks respondents whether they have “a great deal of confidence,” “only some confidence,” or “hardly any confidence at all” in the leaders of different institutions. In 2016, 40% of Americans expressed “a great deal of confidence” in leaders of the scientific community, 50% expressed “only some confidence,” and 6% expressed “hardly any confidence at all” (📊 Figure 7-14). These results are nearly identical to recent years (📊 Figure 7-15; Appendix Table 7-28). In general, men (45%) are more likely to have a “great deal of confidence” in the scientific community than women (36%). Also, those with more education and income are more confident than those with less, and young respondents are more confident than older respondents (Appendix Table 7-29). Some recent research suggests that political views are increasingly related to confidence in science (Gauchat 2012; McCright et al. 2013). Other research suggests a racial gap in confidence (Plutzer 2013).

FIGURE 7-14

Public confidence in institutional leaders, by type of institution: 2016



Note(s)

Responses to the following: *As far as the people running these institutions are concerned, would you say that you have a great deal of confidence, only some confidence, or hardly any confidence at all in them?* Percentages may not add to 100% because of rounding.

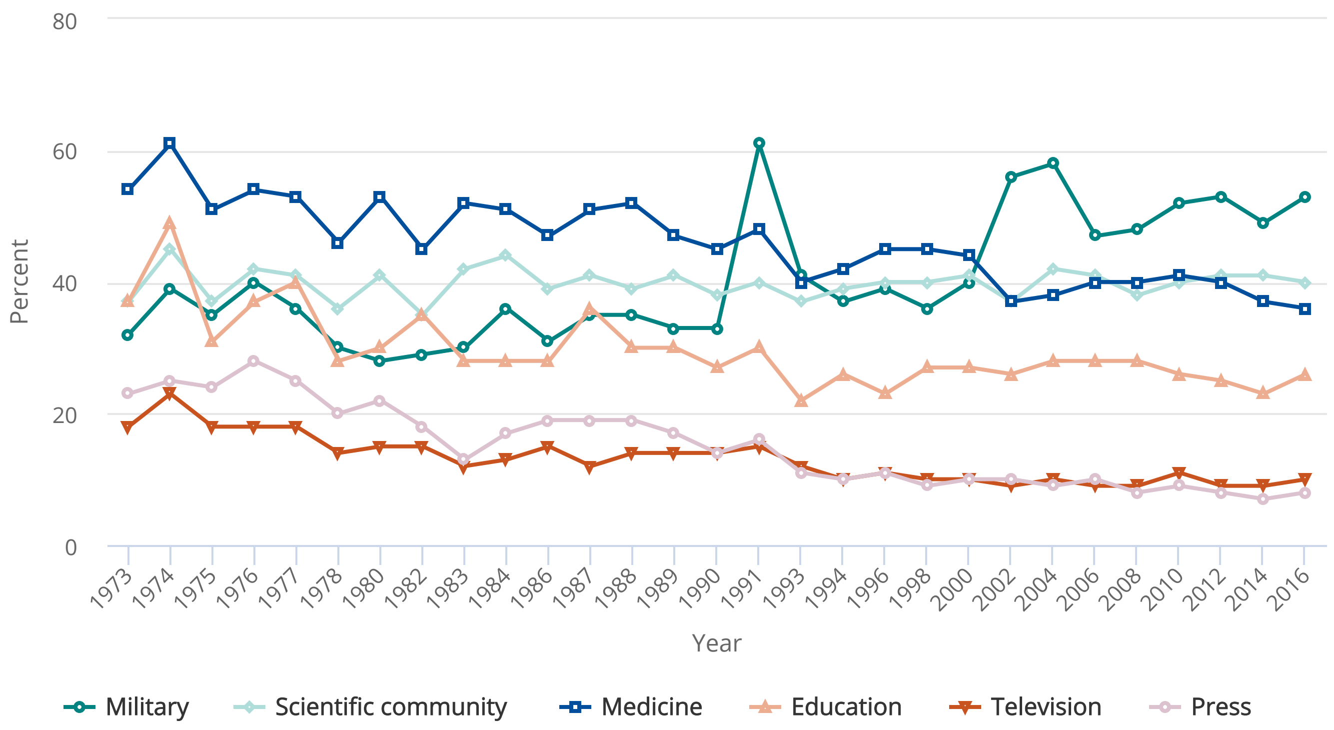
Source(s)

NORC at the University of Chicago, General Social Survey (2016). See Appendix Table 7-28.

Science and Engineering Indicators 2018

FIGURE 7-15

Public confidence in institutional leaders, by selected institution: 1973–2016



Note(s)

Responses to the following: *As far as the people running these institutions are concerned, would you say that you have a great deal of confidence, only some confidence, or hardly any confidence at all in them?* Figure shows only responses for "a great deal of confidence."

Source(s)

NORC at the University of Chicago, General Social Survey (1973–2016). See Appendix Table 7-28.

Science and Engineering Indicators 2018

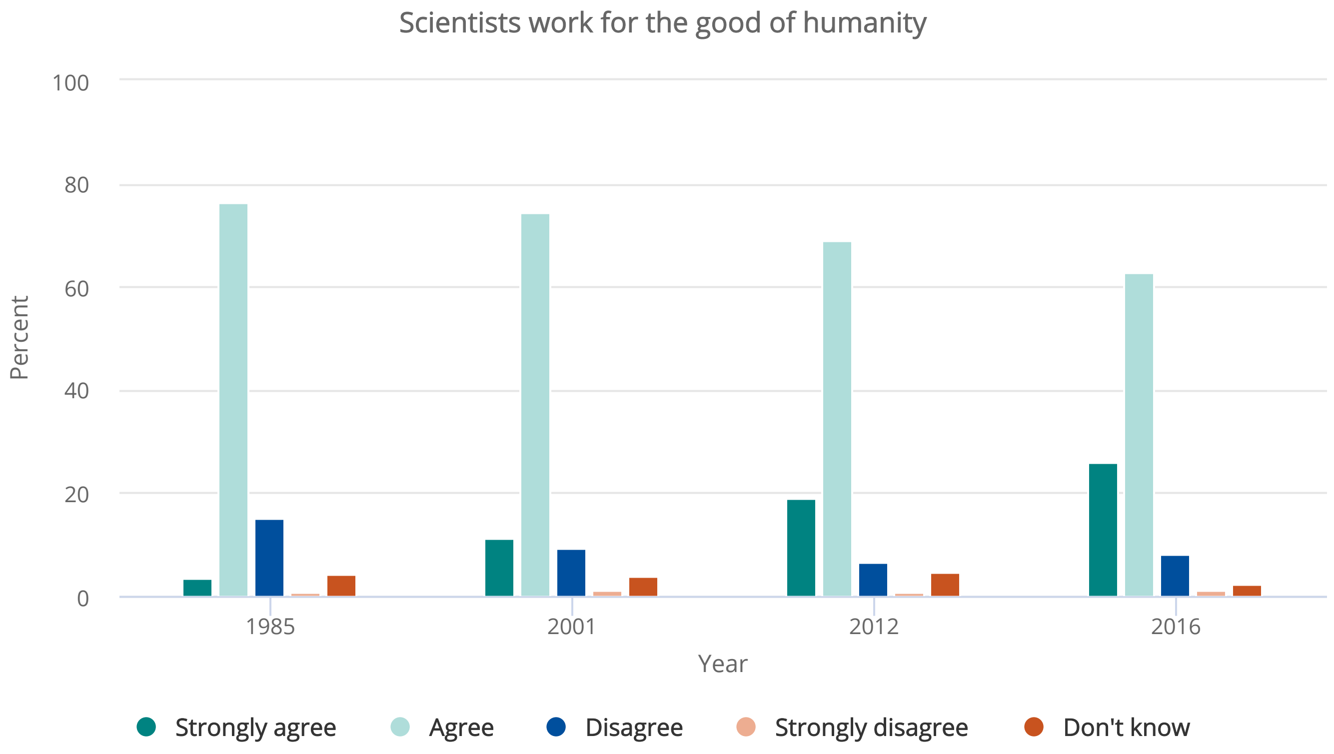
These results also suggest that leaders of the scientific community compare well with leaders of other institutions in America. Only military leaders held greater public confidence in 2016, with 53% of Americans saying they had a “great deal of confidence” in them (Figure 7-14). Most other groups, unlike scientists and the military, have also seen an erosion in public confidence, with the most substantial decreases occurring between the 1970s and 1990s (Appendix Table 7-28 and Appendix Table 7-29).

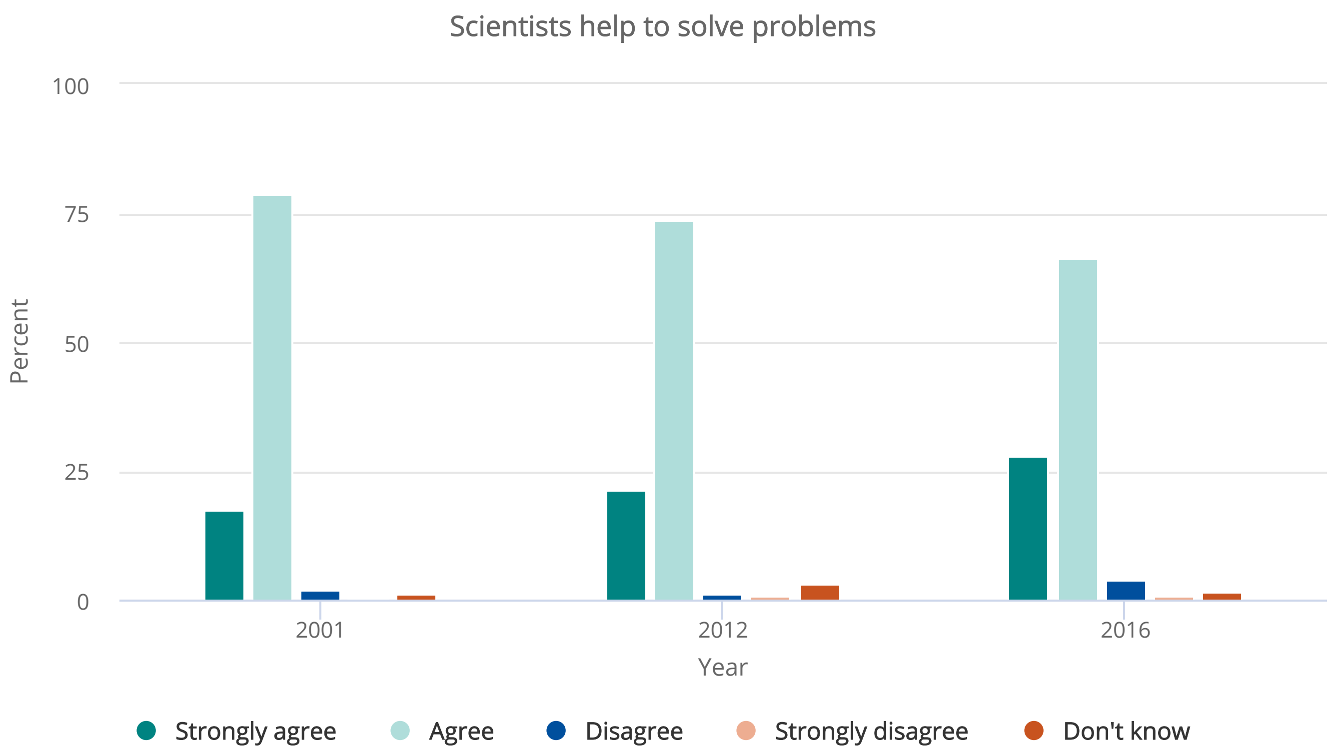
The medical community, which is the only group besides scientists in the survey with a clear S&T focus, is one of the institutions that has seen a substantial decline in perceived confidence. Whereas the percentage of Americans saying they place a “great deal of confidence” in the scientific community has stayed relatively stable since the 1970s, the percentage expressing such confidence in the medical community has fallen from consistently above 50% in the 1970s and 1980s to 37% in 2014 and 36% in 2016 (Figure 7-15).

The 2016 GSS also included a set of specific questions aimed at capturing a more detailed understanding of how Americans see scientists. The responses to these questions reinforce the idea that scientists are seen as both competent and working to benefit society. Specifically, in 2016, 89% of Americans agreed that scientists were working toward the public good, and 88% agreed that scientists wanted to make life better for the average person (Figure 7-16; Appendix Table 7-30 and Appendix Table 7-31). Similarly, 94% of Americans agreed that scientists are "helping to solve challenging problems." Further, while the overall percentage of respondents agreeing has generally stayed stable or improved over time, the percentage "strongly" agreeing has increased substantially. For example, in 2001, 17% of respondents "strongly" agreed that scientists help solve problems, but 28% gave this response in 2016. The percentage of Americans "strongly" agreeing that scientists work for the good of humanity and make life better has also increased since 2001.

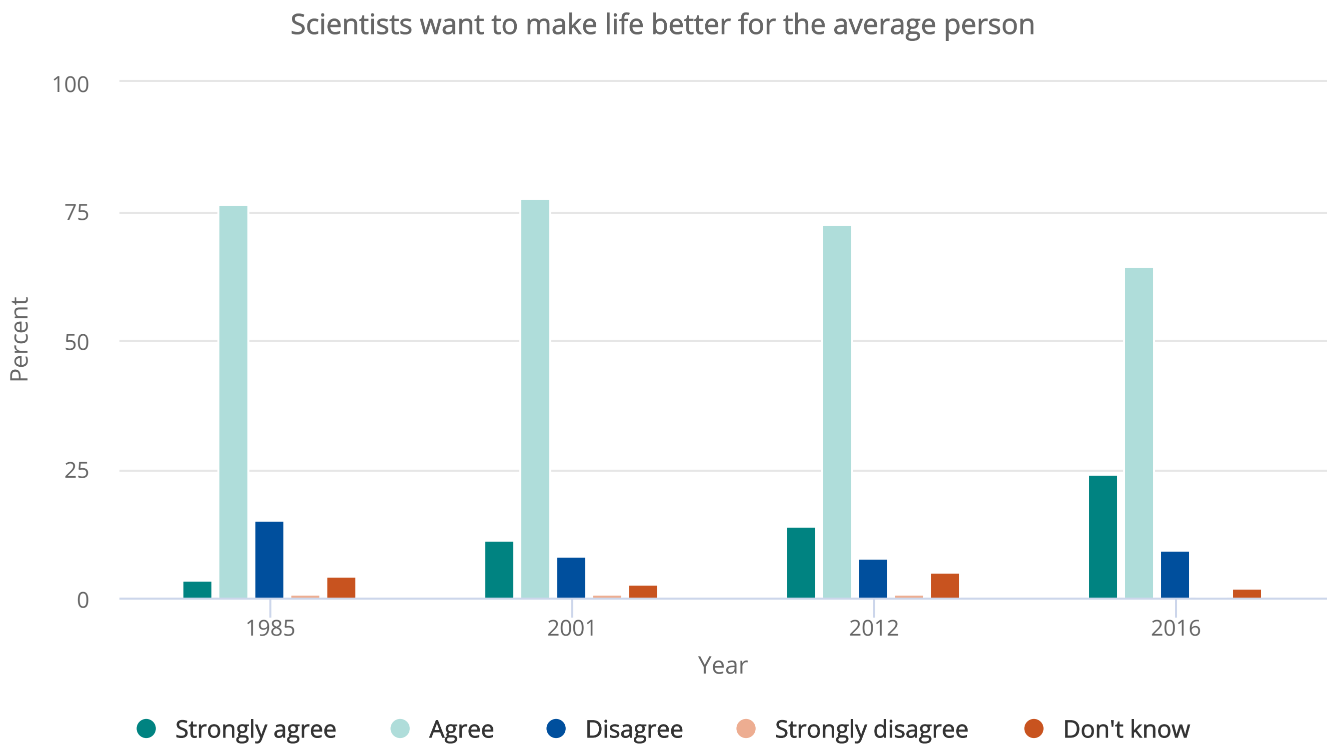
FIGURE 7-16

Public views about scientists: Selected years, 1983–2016

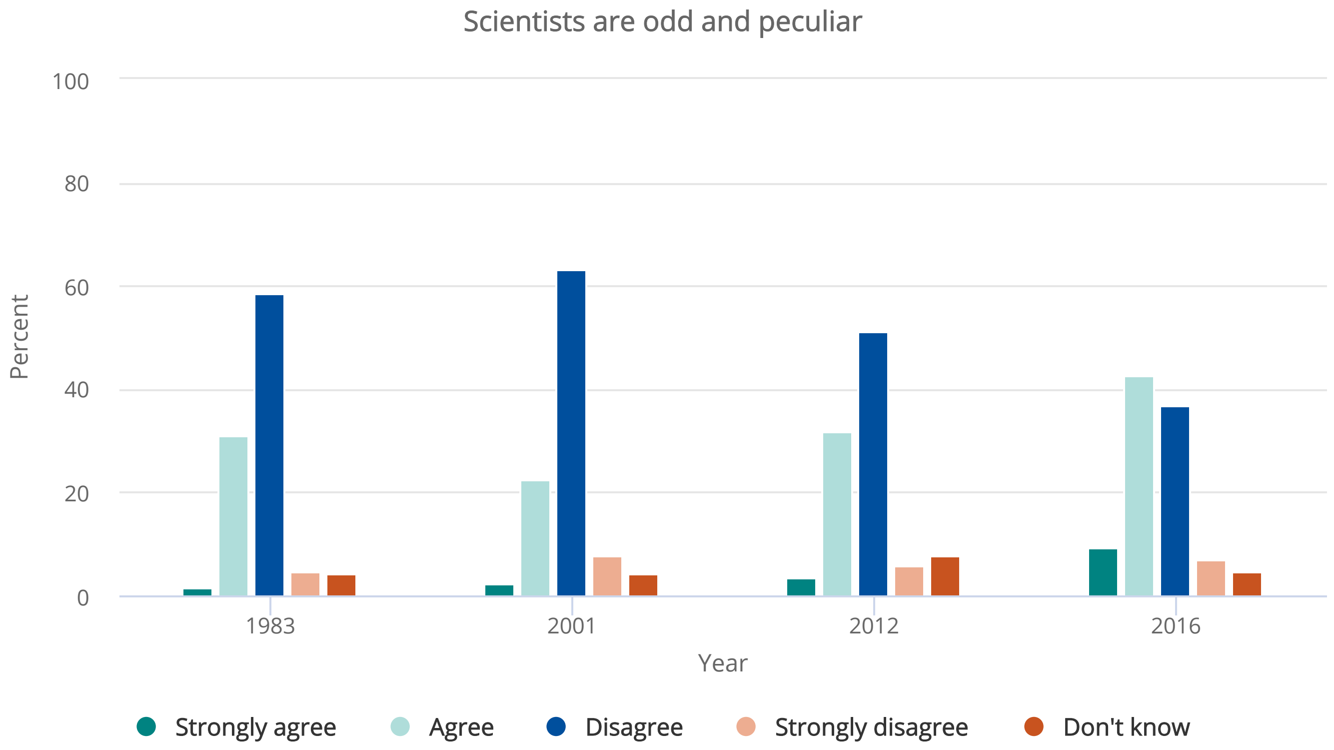




Scientists help to solve problems



Scientists want to make life better for the average person



Note(s)

Responses to the statements *Scientific researchers are dedicated people who work for the good of humanity*; *Scientists are helping to solve challenging problems*; *Most scientists want to work on things that will make life better for the average person*; *Scientists are apt to be odd and peculiar people*. Percentages may not add to 100% because of rounding and because refusals to respond are not shown.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Survey of Public Attitudes Toward and Understanding of Science and Technology (1983, 1985, 2001); NORC at the University of Chicago, General Social Survey (2012, 2016). See Appendix Table 7-30.

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One less positive trend for how scientists are viewed emerged, however, for a question focused on whether Americans see scientists as “odd and peculiar people.” In 2016, about 52% of Americans “strongly agree[d]” (9%) or “agree[d]” (43%) that “scientists are apt to be odd and peculiar people.” This is up from 36% in 2012 and 24% at its lowest, in 2001. Further, in 2016, 58% of those whose highest degree was high school agreed that scientists are “odd and peculiar,” compared to 37% of those with graduate or professional degrees.

The Pew Research Center has also asked about trust in science in specific contexts across three 2016 surveys and has generally found that scientists are more trusted than other groups. For example, 78% of respondents said they had “a lot” (35%) or “some” (43%) trust in scientists to give “full and accurate information about the health risks and benefits of eating genetically modified food.” In comparison, if the categories “a lot” and “some” are combined, 45% said they would trust the “news media,” 42% said they would trust “food industry leaders,” and 25% said they would trust “elected officials” (Funk and

Kennedy 2016b). In another study, 78% said they trusted “climate scientists” to give complete information about “the causes of global climate change,” whereas 44% said they would trust the news media, 41% said they would trust “energy industry leaders,” and about 29% said they would trust “elected officials” (Funk and Kennedy 2016a). Finally, the same pattern was evident when Americans were asked about childhood vaccines for measles, mumps, and rubella. About 90% of Americans said they would trust “medical scientists,” compared to 42% for the “news media,” 49% for pharmaceutical industry leaders,” and 32% for “elected officials” (Funk, Kennedy, and Hefferon 2017).

International Comparisons

Residents of other countries also typically indicate they have positive views about scientists, although the available questions vary substantially, making direct comparison difficult. In China, 41% of respondents said they saw science as an occupation with a positive reputation, and 31% said the same about engineers (CRISP 2016). Only teachers (56%) and doctors (53%) were seen more positively than scientists. In Switzerland, using a 5-point scale, 57% of respondents indicated that they had confidence in scientists, in general, while 63% indicated they had confidence in university scientists and 35% indicated they had confidence in industry scientists (Schafer and Metag 2016). In Finland, 75% of respondents said they had “very” or “fairly” high trust in universities and colleges, and 66% of respondents said they trusted scientific research and the scientific community (FSSI 2016). In South America, 80% of Argentinians said they have a lot of confidence in scientists as sources of information, and 65% said they see being a scientist as prestigious (MCTIP 2015). In Chile, 79% indicated they saw S&E careers as prestigious, with only medicine (85%) being seen as more prestigious (CONICYT 2016).

Some surveys also found evidence of concern about the degree to which scientists communicate with the broader public. In Germany, only 39% of respondents agreed that scientists communicate enough about their work (Wissenschaft im dialog 2016). Similarly, in Switzerland, 45% of survey respondents indicated that they thought scientists should listen more to what ordinary people think (Schafer and Metag 2016). In South America, 62% of Chilean respondents indicated that they felt scientists do not adequately inform the public about the scientists’ research (CONICYT 2016).

The German survey did not include questions about general trust in scientists and instead focused on trust related to specific issues (Wissenschaft im dialog 2016). The survey found that while 53% of respondents said they trusted scientists on the topic of renewable energy, trust dropped to 40% when respondents were asked about climate change and 17% when respondents were asked about genetic engineering of plants (i.e., genetically modified foods).

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[1] Methodological issues make fine-grained comparisons of data from different survey years particularly difficult for this question. For example, although the question content and interviewer instructions were identical in 2004 and 2006, the percentage of respondents who volunteered “about equal” (an answer not among the choices given) was substantially different. This difference may have been produced by the change from telephone interviews in 2004 to in-person interviews in 2006 (although telephone interviews in 2001 produced results that are similar to those in 2006). More likely, customary interviewing practices in the three different organizations that administered the surveys affected their interviewers’ willingness to accept responses other than those that were specifically offered on the interview form, including “don’t know” responses.

Public Attitudes about Specific S&T-Related Issues

In addition to general views about S&T, people also develop views about specific issues and topics, and these views can shape behavior. While Americans appear to have relatively stable, positive views about science in general, there is less stability in how they think and feel about specific issues. The available data suggest that Americans may be increasingly worried about the environment and specific areas of technology with potential health or environmental implications. Such specific attitudes are often shaped by general attitudes and knowledge, but this is not always the case (see sidebar The Relationship between General and Specific Attitudes about S&T). Attitudes about emerging areas of research and new technologies may influence innovation activity in important ways. For example, the climate of opinion about research areas such as biotechnology, energy, or other topics can shape public and private investment in these areas. Ultimately, such views might affect the individual or societal adoption of new technologies and the growth of industries based on these technologies.

Nevertheless, public opinion about new S&T developments rarely translates directly into actions or policy. Instead, institutions attempt to assess what the public believes and may magnify or minimize the effects of divisions in public opinion on policy (Jasanoff 2005). The public's attitudes about specific S&T issues such as climate change and biotechnology can differ markedly from the views of scientists, according to the Pew Research Center (Funk, Rainie, and Page 2015). This is partly because attitudes toward S&T involve a multitude of factors, not just knowledge or understanding of the relevant science (NASEM 2016a). Values, attitudes, and many other factors come into play, and judgments about scientific facts may become secondary or even be shaped by those values or attitudes (Kahan, Jenkins-Smith, and Braman 2011).

This section describes views on environmental issues, including global climate change, nuclear power, and energy development; genetically engineered food; nanotechnology; cloning and stem cell research; and animal research. A sidebar also addresses views about privacy in a digital world, a subject for which public opinion data are only beginning to become available (see sidebar Americans' Attitudes toward Information Privacy in the World of Big Data). Previous versions of *Indicators* have also included data on topics such as synthetic biology and views about science education, but these are not included here because of a lack of new national data from representative surveys. As with the rest of *Indicators*, the focus is on descriptive statistics for key indicators that became available since the previous report (NSB 2016), including trends and between-group differences. Where appropriate, academic research on the origins of opinions or their effects is cited to provide context. International data are provided, where possible, but there are several issues for which there is little recent available information.

SIDEBAR

The Relationship between General and Specific Attitudes about S&T

Attitudes about specific issues, such as genetic engineering, nanotechnology, and genetically modified (GM) food, can be based on general attitudes and knowledge, but this is not always the case. An analysis of the relationship between general and specific attitudes about S&T finds that the association between the two is, at best, small.

The NSF S&T survey on which the current chapter is largely based has typically focused on general knowledge and attitudes toward science, and the chapter has relied on data from organizations such as Gallup and the Pew Research Center to discuss specific S&T attitudes. However, the 2016 NSF S&T survey included several questions about specific issues that were drawn from past rounds of the GSS.

In looking at the relationship between general and specific attitudes, no attempt is made to suggest that one type of attitude caused the other because it seems possible that respondents may sometimes use their views about specific S&T issues and technologies to develop an overall view about S&T, and vice versa.

Researchers interested in the relationship between the two types of survey questions examine how closely the two move together, on average.

The NSF S&T survey has a 5-point measure of whether the respondent believes that scientific research has produced benefits or harmful results. Each respondent is marked as choosing 1 of 5 responses ranging from believing the harm benefit balance is “strongly in favor” of harm or “strongly in favor” of benefits (see Perceived Promise and Reservations about S&T).

Similarly, respondents in the current survey could indicate the degree to which they believed that pollution of America’s rivers, lakes, and streams was between “not dangerous” and “extremely dangerous” using 1 of 5 response options.

There is little relationship between these two measures, however. On average, when a respondent’s belief in the benefits of science goes up by a point, there is less than a 0.01-point shift in views about the danger of water pollution. Similarly, a 1-point change in views about the benefits or harms of science is associated with a less than 0.01-point average shift in views about the danger of industrial air pollution and global warming.

There was also no meaningful relationship between the three environment-focused questions and the degree to which respondents said they disagreed or agreed that science was making life change too fast or creating opportunities for future generations (see Perceived Promise and Reservations about S&T for the exact questions).

There were, however, small meaningful relationships between general science attitudes and attitudes about specific technologies such as nuclear energy, genetic engineering, and nanotechnology (all of which were measured with 5-point response options focused on perceived danger).

For GM foods and nuclear energy, a 1-point change in perceived general benefits of S&T was associated with about a 0.2-point average decrease in perceived technological danger. Similarly, 1-point changes in the belief that S&T would result in more opportunities for future generations or that science was *not* making our life change too fast were associated with about 0.2-point changes in perceived danger of GM foods and nuclear energy.

For nanotechnology, a 1-point change in perceived benefits (versus harms) was associated with a 0.3-point increase in belief that science would make life better and a 0.5-point decrease in the belief that science is making life change too fast.

The slightly larger relationship between views about nanotechnology and general attitudes about science may reflect the fact that respondents are more likely to draw on their general attitudes when faced with questions about a relatively novel technology.*

* Also of note is that the relationships between general attitudes about science and attitudes about specific technologies tend to remain statistically meaningful even after statistically controlling for general education level and the number of mathematics and science courses the respondent took in high school and college.

SIDEBAR

Americans' Attitudes toward Information Privacy in the World of Big Data

Public and private organizations are collecting an unprecedented amount of data, what many call *big data*, on Americans through social media, Internet logs and trackers, sensor networks, and, increasingly, the Internet of Things (i.e., Internet-connected refrigerators, thermostats, lamps, watches, transportation systems, smart city sensor networks, surveillance devices, etc.). These developments offer the promise of a future in which government and business can more easily identify and address consumer and citizen needs and understand societal problems. Simultaneously, however, big data raises questions about the protection of privacy and possible adverse uses of personal information.

Surveys indicate that Americans highly value information privacy, both in terms of what is gathered and by whom. Trust in the integrity of the data gathering agents is low. Most Americans claim to have reduced their online visibility, but more than half—and up to three-quarters—register lack of knowledge of privacy tools and how to employ them. Despite saying they value information privacy, Americans readily share information, a puzzle that researchers call the *privacy paradox*.

The Importance of Privacy

Most Americans indicate in surveys that information privacy is "very important" to them. In a 2015 survey, about three-fourths of respondents (74%) indicated it was very important for them to control *who* can get information about them, and 65% considered it very important to control *what* information is collected about them (Madden and Rainie 2015). Ninety percent or more said that these types of control are somewhat important to very important.

Perceived Privacy Threats

While Americans view privacy as important, they also believe their privacy is threatened. In 2013, only 9% of Americans surveyed said they believed they have "a lot" of control over the information collected about them by electronic means in daily life. About half of Internet users among those surveyed worried about how much information is available about them online in 2013, an increase over the 33% who said they were worried in 2009 (Rainie et al. 2013).

In a 2014 poll, few people trusted that various organizations would keep their personal information secure. Two percent of Americans expressed trust in social networking websites or applications; 6% trusted online retailers; and 12%–19% trusted federal or state governments, e-mail providers, and cellphone carriers. At the high end, 26% trusted health insurance companies, and 39% banks and credit card companies (Fleming and Kampf 2016; Madden and Rainie 2015).

Adaptation

Given their belief in the importance of privacy and concerns about threats to privacy, Americans may adapt their behavior to improve their privacy. The vast majority (86%) of Internet users said they had taken steps to reduce their visibility online (Rainie et al. 2013). Further, people's reported willingness to share private information appears to vary by context, including which organization is getting the information, what the organization will do with it, and what the consumer gets in return (Rainie and Duggan 2016). Young adults (18–29 years old) reported being more likely than other age groups to seek greater anonymity online (Madden and Smith 2010; Rainie et al. 2013).

The Challenges of Adaptation

Despite saying they have taken steps to improve their privacy online, Americans feel they should do more but are unclear on just what to do. In a 2014 survey, about 61% of respondents said they felt they "would like to do more" (Madden 2014). In a 2015 survey, however, 54% indicated that finding tools to improve their privacy was "somewhat" or "very" difficult, and many said they were unaware of specific privacy tools (Rainie and Madden 2015). Seventy-four percent disagreed or strongly disagreed that it was easy for them to be anonymous online, with larger percentages of more knowledgeable users disagreeing more strongly (Madden 2014). Nearly half of Americans in a 2015 survey indicated they were not confident they understood how their data would be used when deciding whether to share it (Pew Research Center 2015b).

Researchers who study privacy have found a *privacy paradox*—while people indicate strong general concern over privacy, observations of their actual behavior show that they readily divulge personal information (Smith, Diney, and Heng 2011; Wilson and Valacich 2012). They give such information in exchange for small discounts, personalization, online social interaction, and other inducements (Chellappa and Sin 2005; Norberg, Horne, and Horne 2007; Pötzsch 2009; Spiekermann, Grossklags, and Berendt 2001).

Privacy researchers have proposed several potential explanations for this apparent paradox, including concerns that conventional surveys do not obtain adequately considered opinions, thus giving an exaggerated impression of people's privacy concerns in real decision making (Baek 2014). When divulging private information, people get few indications about potential privacy dangers but do receive clear indications about benefits and the apparent trustworthiness of the organization asking for information (Acquisti, Brandimarte, and Loewenstein 2015; Li, Sarathy, and Xu 2011; Norberg, Horne, and Horne 2007; Pötzsch 2009; Wilson and Valacich 2012). People are not sufficiently knowledgeable or certain about how technology affects privacy (Acquisti, Brandimarte, and Loewenstein 2015; Pötzsch 2009). Also, people ignore future risk or are unable to weigh the complex benefits and costs of sharing information (Acquisti 2009; Acquisti and Grossklags 2003; Tsai et al. 2011; Wilson and Valacich 2012). Researchers disagree as to whether people's attitudes or behaviors are better guides to their rational preferences.

Many technology experts believe that the public will experience greater difficulty protecting their privacy as technology progresses (Rainie and Anderson 2014). In 2014, 64% of the public said they wanted government to "do more to regulate what advertisers do with customers' personal information," according to the Pew Research Center (Madden 2014).

Environment

This section provides information on the public's views about the environment, specific environmental issues, energy technologies, and climate. Overall, the evidence suggests that, while general views about S&T are largely stable, Americans recently have become more concerned about a wide range of environmental issues. Some of these issues—especially climate change and energy technologies—are often the subject of public policy debate and news interest.

Overall Concern about Environmental Quality

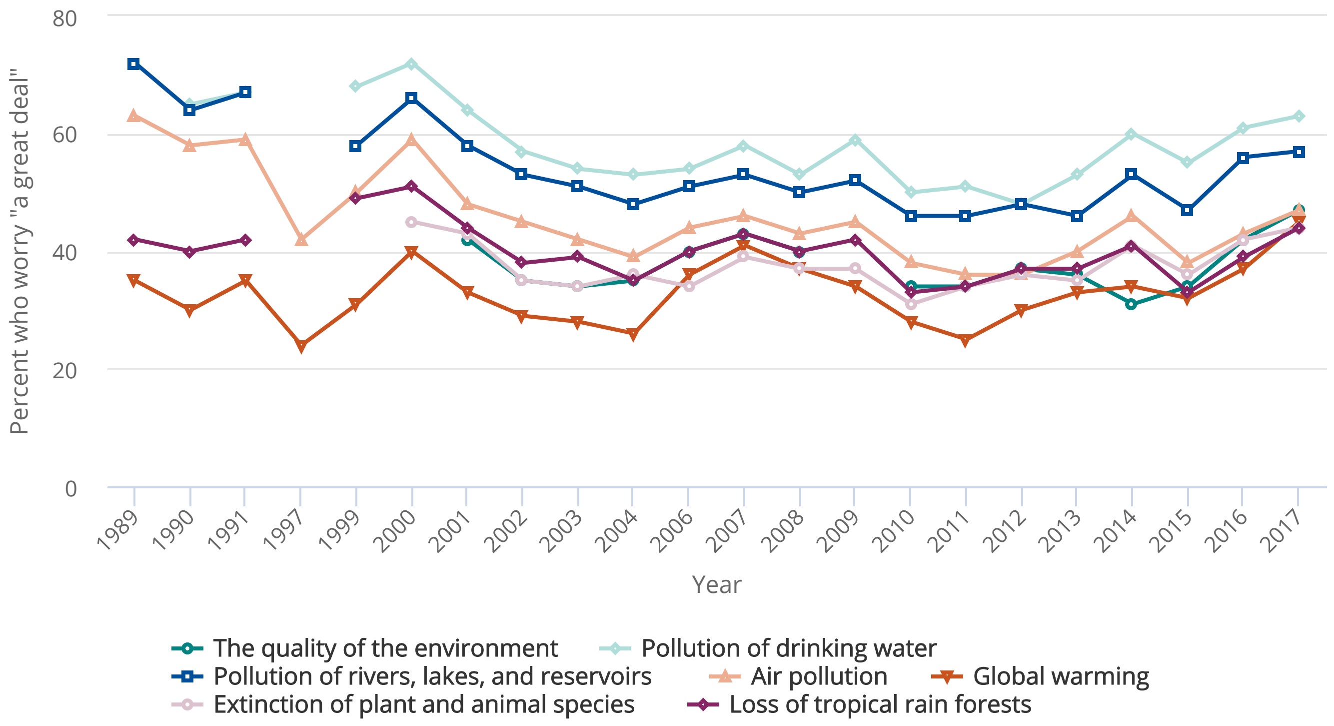
U.S. Patterns and Trends

Overall, measured U.S. concern about the environment appeared to reach a new high in 2017, just 3 years after hitting a historic low. In 2017, about 47% of respondents said that they personally worry a "great deal" about the quality of the environment (Gallup 2017b) (Figure 7-17). Another 30% said they worried a "fair amount." The previous high had been the 43% who expressed a "great deal" of worry in 2007, while the previous low had been 31% in 2014. The percentage of Americans saying that the quality of the environment is getting worse grew to 56% in 2016 and 57% in 2017 after hovering between 49% and 51% between 2009 and 2015. The current level of belief in a worsening environment is still relatively low compared to 2008, when 68% of Americans said they thought the environment was getting worse. And, while worry about the future is high, Americans' rating of the current overall quality of the environment was similar to historical averages in 2016. About 46% rated the environment as excellent (6%) or good (40%), similar to previous years.

For comparison, the availability and affordability of health care was the issue with which the highest proportion of Americans expressed a "great deal" of worry in 2017 (57%) (Newport 2017). The percentage expressing a "great deal" of worry about the environment (47%) was similar to a number of other issues, including crime and violence (47%), hunger and homelessness (47%), the economy (46%), and federal spending and the budget deficit (49%).

FIGURE 7-17

Concern about specific environmental issues: 1989–2017



Note(s)

Data are not available for all years. Responses to the following: *How much do you personally worry about [specific environmental issues]: a great deal, a fair amount, only a little, or not at all?* Figure shows only responses for "a great deal." Poll is conducted annually in March.

Source(s)

Gallup, Climate Change: Environment, http://www.gallup.com/poll/1615/environment.aspx#, accessed 12 April 2017.

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International Comparisons

Within Europe, a 2014 Eurobarometer survey on the environment included a broad range of questions about attitudes and behavior (European Commission 2014b). As is often the case with international data, these questions are not always directly comparable to those for the United States in terms of wording and how respondents are selected for inclusion in a survey. Overall, 95% of Europeans said that protecting the environment was “very important” (53%) or “fairly important” (42%), similar to 2011 (94%). About three-quarters of respondents (77%) also indicated that they “totally agreed” (35%) or “tend[ed]” to agree that environmental issues have a direct impact on their daily life. This was also stable from 2011 when 76% agreed (see [NSB 2016] for a discussion of specific countries).

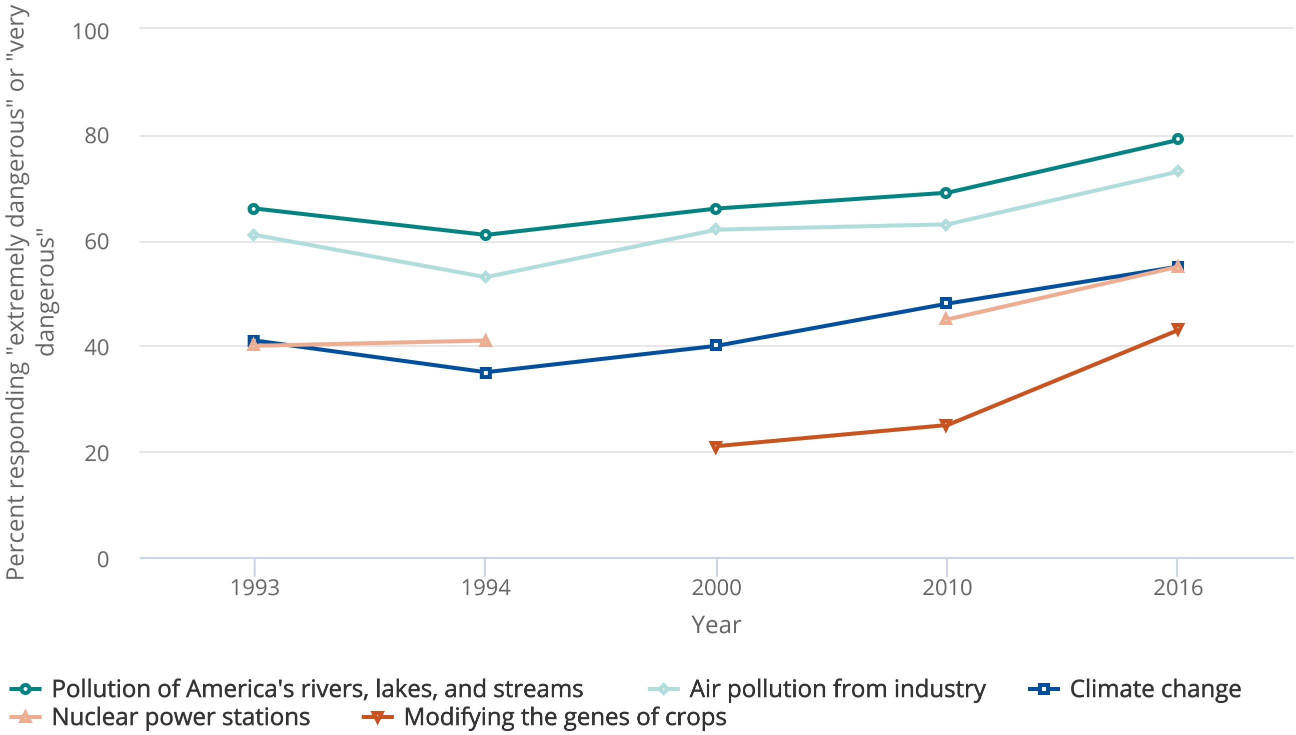
Assessment of Specific Environmental Problems

U.S. Patterns and Trends

The 2016 GSS included several questions about specific environmental issues. These questions had previously appeared as part of the GSS in 1993, 1994, 2000, and 2010, and this makes it possible to provide a limited discussion of possible changes over time (Figure 7-18; Appendix Table 7-32 and Appendix Table 7-33). Gallup collects annual data on public opinion about a wide range of environmental issues against which the GSS can sometimes be compared. In addition to the specific findings, it is noteworthy that worry about specific environmental issues move together over time along with worry about the overall quality of the environment.

FIGURE 7-18

Perceived danger of specific health and environmental issues: Selected years, 1993–2016



Note(s)

Data are not available for all years. Data show the percentage of respondents giving a response of "extremely dangerous" or "very dangerous" to the following questions: *In general, do you think that pollution of America's rivers, lakes, and streams is...*; *In general, do you think that air pollution caused by industry is...*; *In general, do you think that a rise in the world's temperature caused by the 'greenhouse effect' is...*; *In general, do you think that nuclear power stations are...*; and *Do you think that modifying the genes of certain crops is....*

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Survey of Public Attitudes Toward and Understanding of Science and Technology (1993, 2000); NORC at the University of Chicago, General Social Survey (2010, 2016).

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Water pollution is the environmental issue that most concerns Americans. According to the GSS, about 79% of Americans in 2016 said they thought water pollution was “extremely” or “very” dangerous to the environment; this proportion has grown since 1994, when the percentage was 61% (66% in 1993) (Appendix Table 7-32). Gallup (2017b) also found that water issues were the environmental topics that most concerned Americans. About 61% of Americans expressed a “great deal” of worry about drinking-water pollution in 2016, and 63% expressed this level of worry in 2017. In 2016 and 2017, respectively, about 56% and 57% of Americans reported similar levels of worry about pollution of rivers, lakes, and reservoirs.

After water pollution, air pollution was the next issue about which the highest proportion of Americans worried. Within the GSS data, 73% of Americans said they felt that industrial pollution presented a high level of danger in 2016, and this percentage grew from a low of 53% in 1994 (61% in 1993) (Appendix Table 7-33). Gallup (2017b) found that 43% of Americans expressed a "great deal" of worry about air pollution in 2016, and this grew to 47% in 2017.

Concern about water and air pollution is fairly evenly distributed across demographic groups within the GSS, although those with relatively lower levels of education have somewhat lower average concern. Higher levels of science knowledge were also associated with more concern about water (Appendix Table 7-32 and Appendix Table 7-33). For example, about 67% of those in the lowest quartile of knowledge said they thought water pollution was "extremely or very dangerous," whereas 84% of those in the top quartile of science knowledge had such views (Appendix Table 7-32). For industrial air pollution, only those in the lowest quartile of science knowledge were substantially different, with 67% indicating they saw such pollution as "extremely dangerous or very dangerous" compared to 73% of those in the second quartile of knowledge, 75% of those in the third quartile, and 76% of those in the top quartile (Appendix Table 7-33).

Gallup also collects data on public concern about extinction and the loss of tropical rain forests. In 2017, 44% of Americans said they worried "a great deal" about the extinction of plant and animal species, and the same percentage said they worried "a great deal" about the loss of tropical rain forests. These responses are somewhat lower than worry about water or air pollution but higher than worry about climate change.

One noteworthy difference between the Gallup data (📊 Figure 7-17) and the NSF data within the GSS (📊 Figure 7-18) is that the Gallup data show a drop in concern about various environmental issues between about 2000 and 2010. In contrast, the NSF data show no such pattern. However, both Gallup and NSF data show increasing concerns after 2010.

International Comparisons

The 2014 Eurobarometer on the environment asked respondents to indicate the 5 main environmental issues that they were worried about from a list of 14. Although water pollution was the issue most worried about in the United States, air pollution (56%) was the most commonly named issue in Europe. This was followed by water pollution (50%), the growing amount of waste (43%), the health effect of chemicals used in everyday products (43%), and the depletion of natural resources (36%). Climate change was not included on the list because it was the focus of a separate report earlier in 2014 (European Commission 2014).

Climate Change

U.S. Patterns and Trends

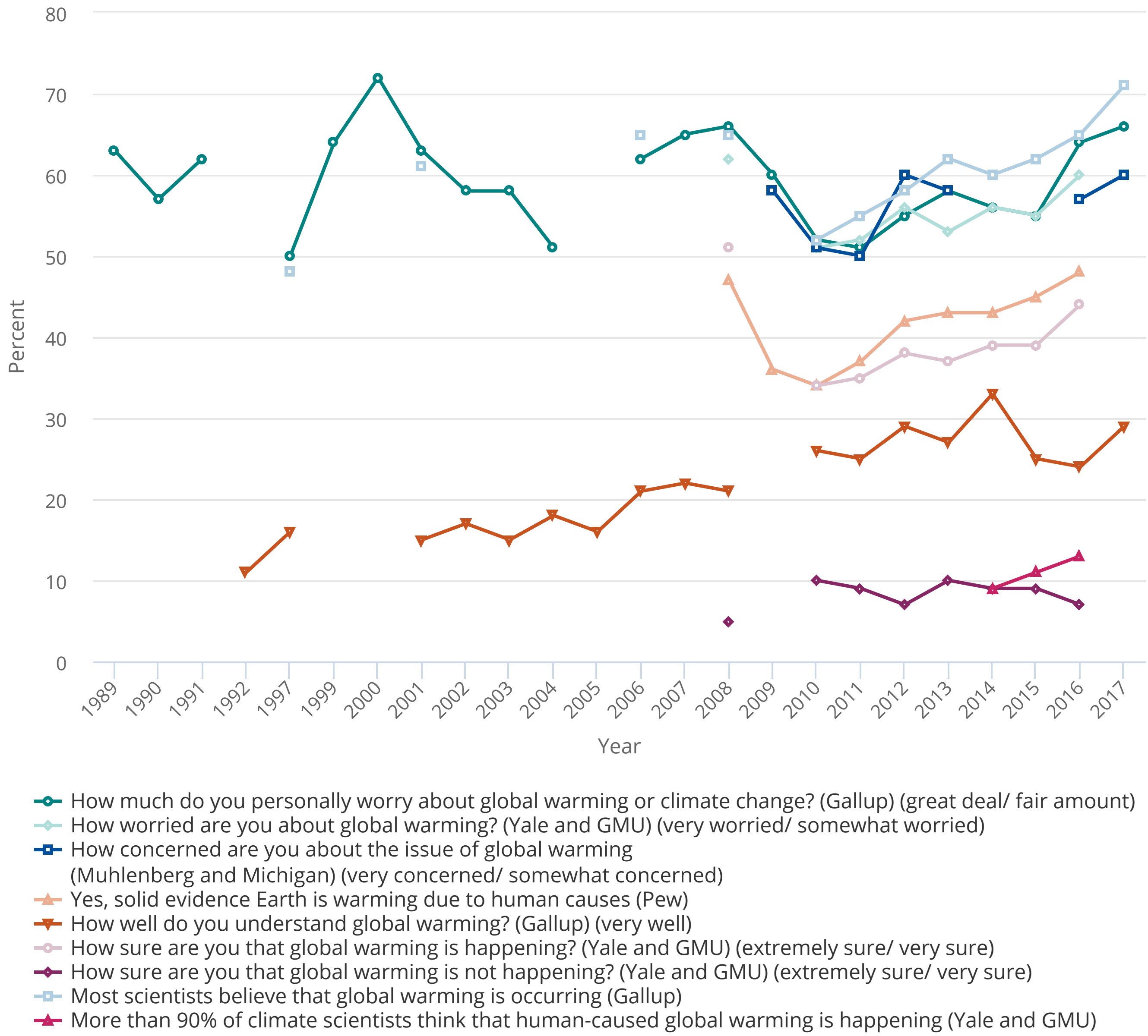
Climate change (often referred to as *global warming, especially in past decades*) remains a central, and often divisive, environmental issue for many Americans, even though scientists point out that scientific evidence overwhelmingly supports the conclusion that climate change is already occurring, that it will have a wide range of negative effects on Americans and residents of other countries, and that it is largely the result of human activities (NAS and Royal Society 2014). The importance of this issue to national and international debates about policy and economic implications means that it has also been the subject of widespread polling over more than two decades.[1] Overall, the available data suggest that the percentage of Americans in 2017 who accept that climate change is partly caused by humans and who are concerned about this phenomenon are approaching past highs. This is consistent with overall increasing concern about the environment in recent years. Different question wording, however, can result in somewhat different results, and it is therefore helpful to look for patterns of response over time and across surveys. It is also worth separately considering overall concern about climate change, belief that climate change is occurring, and views about whether scientists agree among themselves.

With regard to concern, a single question in the GSS about climate change suggests that 55% of Americans think that a rise in the world's temperature caused by the *greenhouse effect*—an earlier term used in discussions of climate change that is used here to preserve comparability over time—is either "extremely dangerous or very dangerous" (Appendix Table 7-34). This is up from the low of 35% in 1994 (and from 41% in 1993 and 40% in 2000). The 2016 percentage is also higher than the results of a 2010 GSS question—using the term *climate change*—that found that 48% of Americans saw high levels of danger from the phenomenon.

The relatively high levels of concern about climate change seen in the GSS data are consistent with data from Gallup (Saad 2017). Gallup has polled on "global warming" since 1989, when it found that 63% of Americans worried a "great deal" (35%) or a "fair amount" (28%) about the issue. In March 2017, the comparable statistic was similar with 66% saying they either worry a "great deal" (45%) or a "fair amount" (21%) (Figure 7-19). This indicator, however, has fluctuated between a low of 51% (2004) and a high of 72% (2000). A data series from the University of Michigan and Muhlenberg College (2017) that began in 2009 also suggests a similar pattern within recent years. According to these surveys, the percentage of Americans who were "very" or "somewhat concerned" fell from 58% in 2009 to 50% in 2011 but then increased to 60% in 2012.

FIGURE 7-19

Belief in global warming and confidence in that belief: 1989–2017



GMU = George Mason University.

Note(s)

Questions were not asked in all years. *How concerned are you about the issue of global warming?* (Muhlenberg and Michigan) was asked in 2017, 2016, 2012, 2011, and 2009 only of respondents who answered yes to the question *From what you've read and heard. Is there solid evidence that the average temperature on earth has been getting warmer over the past four decades?* In 2013, a split sample of the entire sample (*n* = 947) was used, with 477 respondents asked about "global warming" and 470 respondents asked about "climate change." However, responders to *How concerned are you about the issue of global warming?* are shown as percentages of the total population.

Source(s)

Pew Research Center, *The Politics of Climate,* http://www.pewinternet.org/2016/10/04/the-politics-of-climate/, accessed 16 February 2017, *Public and Scientists' Views on Science and Society* (2015), http://www.pewinternet.org/files/2015/01/PI_ScienceandSociety_Report_012915.pdf, accessed 16 February 2017, and *Catholics Divided Over Global Warming* (2015), http://www.pewforum.org/files/2015/06/Catholics-climate-change-06-16-full.pdf, accessed 16 February 2017; Gallup, Climate Change: Environment, https://www.gallup.com/poll/1615/environment.aspx#, accessed 16 February 2017, and Gallup Social Series: Environment, Final Topline 1–5 March 2017; Leiserowitz A, Maibach E, Roser_Renouf C, Rosenthal S, Cutler M, *Climate Change in the American Mind: November 2016*, Yale University and George Mason University, New Haven, CT: Yale Program on Climate Change Communication (2017), http://climatecommunication.yale.edu/wp-content/uploads/2017/01/Climate-Change-American-Mind-November-2016.pdf, accessed 16 February 2017; Leiserowitz A, Maibach E, Roser-Renouf C, Feinberg G, Rosenthal S, *Climate Change in the American Mind: March 2015,* Yale University and George Mason University, New Haven, CT: Yale Program on Climate Change Communication (2015), https://environment.yale.edu/climate-communication/files/Global-Warming-CCAM-March-2015.pdf, accessed 16 February 2017; Muhlenberg College and the University of Michigan, National Surveys on Energy and Environment, http://closup.umich.edu/national-surveys-on-energy-and-environment/nsee-survey-pages.php, accessed 22 June 2017.

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It is also noteworthy that, within these data, the percentage saying they worry a “great deal” about climate change reached a new high of 45% in 2017. Much of the shift seems to come from the percentage saying that they worry a “fair amount,” which shrank from 27% in 2016 to 21% in 2017. A similar percentage of people are not particularly concerned about climate change. The percentage saying they worry about climate change “only a little” stayed about the same (18% in 2017, similar to previous years). The percentage reporting “no worry at all” about climate change went from 19% in 2016 to 16% in 2017, having dropped from a high of 29% in 2010.

Also, while about two-thirds of Americans say they worry about global warming, 42% told Gallup in 2017 that they believed “global warming would pose a serious threat” to their way of life in their lifetime. This suggests that some of those who worry about global warming perceive the negative impacts of climate change to be more long term rather than immediate. As with the question about *worry about global warming*, responses to the “serious threat” question have fluctuated over time, although the level has stayed between 31% (2001) and 40% (2008) since 2001. In the short term, this number has risen from 34% in 2013 (Saad 2017).

Data from researchers at Yale University and George Mason University (GMU) (Leiserowitz et al. 2017) and the Pew Research Center (Funk and Kennedy 2016a) show similar patterns. The Yale-GMU scholars also found that Americans think that a range of negative events are becoming more likely because of climate change, including more severe weather (Leiserowitz et al. 2017). The Pew Research Center further found that about 78% said they thought storms were “very” (42%) or “fairly” (36%) likely to become more severe. Similar proportions of Americans said they thought it was at least “fairly” likely that climate change would cause rising sea levels that erode beaches and shorelines (76%), more drought or water shortages (76%), damage to forests and plant life (77%), and harm to animal wildlife and their habitats (77%) (Funk and Kennedy 2016a).

Scientific research points to humans as a primary force behind climate change. However, while most Americans agree climate change may be occurring, many believe that these changes are part of natural cycles. Data from the Pew Research

Center (Funk and Kennedy 2016a) show that 48% of respondents tended to believe that the Earth is getting warmer, mostly because of human activity, such as burning fossil fuels. Another 26% said they thought the Earth is getting warmer "mostly because of natural patterns." The percentage pointing to "human activity" as the cause of temperature changes represents an increase from the Pew Research Center's (2015a) data for recent years, where belief in a human cause dipped as low as 36% in 2011, but is largely consistent with public attitudes from the mid-2000s, when belief in a human cause of climate change peaked at 50% (2006). Gallup reported in 2017 that 68% of Americans believe that human activities are the most important cause of climate change, while 29% attributed warming to natural causes (Saad 2017). In 2016, 63% of Gallup respondents attributed global warming to humans. The previous high had been 61% (a high reached in 2001, 2003, and 2007). The differences between the Pew Research Center and Gallup data likely reflect question wording. The Gallup question asks respondents to choose between human or natural causes, whereas the Pew Research Center provides a range of options.

Many Americans also do not appear to know that the vast majority of scientists believe there is solid evidence of climate change and that humans are the dominant cause. The extent to which Americans are unaware of this, however, varies based on the survey; again, question wording likely accounts for much of the difference in the responses. The Yale-GMU research (Leiserowitz et al. 2017) found that only 15% of their respondents said that they thought more than 90% of climate scientists "have concluded human-caused global warming is happening." The Pew Research Center reported that about 27% of its respondents believed that "almost all" climate scientists say that "human behavior is mostly responsible for climate change" (Funk and Kennedy 2016a). Gallup found that 71% of Americans said they thought "most scientists" believe "global warming is occurring" (Saad 2017). This surpasses the previous high of 65% in 2015.

International Comparisons

The most recent internationally comparable, representative data on public views about climate change continue to suggest that, on average, about 7 in 10 of those surveyed in a range of countries see climate change as serious. In this regard, Americans appear relatively less concerned about the issue than residents of most other countries. A 2015 multicountry study by the Pew Research Center found that the United States, countries in the Asia-Pacific region such as China, and countries in the Middle East had relatively low levels of concern about global change compared to residents of Europe, Africa, and Latin America (Stokes, Wike, and Carle 2015). For example, 74% of American, 75% of Chinese, and 79% of Jordanian respondents said "global climate change" was at least "somewhat" serious, while 93% of French, 87% of German, and 91% of Italian respondents gave such a response. Further, in South America, 98% of Brazilians, 98% of Chileans, and 93% of Mexicans said they saw climate change as serious. In Africa, 92% of Ugandans, 89% of Kenyans, and 84% of Nigerians said they saw climate change as serious. Related questions showed similar patterns of response, although there were typically some countries in each region (except South America) where attitudes about the seriousness of climate change were more like those held in the United States. These countries were among the least concerned within their regions and included, for example, the UK (77%), Turkey (74%), Indonesia (74%), and South Africa (73%). The countries where the smallest percentage of people said they saw climate change as serious were Pakistan (65%) and Israel (67%), although Pakistan had an unusually high number of respondents (19%) who chose not to answer the question or said they did not know if climate change was a serious problem.

Within Europe, the European Commission (2015) conducted a special Eurobarometer in 2015 on climate change that found that 91% of Europeans see climate change as a problem. Specifically, respondents were asked to use a 10-point scale, where 1 indicated "not at all a serious problem" and 10 indicated "an extremely serious problem," and found that 69% chose a number between 7 and 10 and another 22% chose 5 or 6. The overall numbers were nearly identical to the results of surveys in 2011 and 2013, but there were still changes within countries. There was also substantial variation between countries. For example, 87% of Greeks, 81% of Italians, and 80% of Bulgarians gave an answer of 7 or higher, but only 37% of Latvians, 53% of those in the UK, and 58% of the Dutch gave such a response. Many of the largest European countries were near the European average. For example, about 69% of French, 72% of Germans, and 79% of Spaniards chose between 7 and 10. The biggest changes were in Eastern Europe. In Bulgaria, the responses between 7 and 10 increased 13 percentage points to 80%; in Romania, the responses rose 11 percentage points to 74%. The biggest declines were in Austria and Slovakia. Austria declined 8 percentage points to 69%, and Slovakia declined 12 percentage points to 68%.

Energy

U.S. Patterns and Trends

Public opinion about energy has also fluctuated in recent years in response to accidents such as the 2011 nuclear accident in Fukushima, Japan, changing energy prices, and the emergence of issues such as hydraulic fracturing (sometimes termed *fracking*) as a technique to extract natural gas from the Earth. The range of energy events and issues, however, means that although specific events may have short-term effects, consistent long-term trends in public opinion about energy are rare. Overall, 23% of Americans said that “the energy situation in the United States” was “very serious” in 2017 (Newport 2017), down from recent highs of 45% in 2011 and 46% in 2008—when, for example, gasoline prices were relatively high. The 2017 figure is thus close to a historic low in concern. Similarly, the percentage of Americans saying that they worried “a great deal” about “the availability and affordability of energy” matched historic lows of 27% in both 2016 and 2017, a period of relatively low gas prices compared to recent years. The last time worry was as low was 2003, a year in which gas prices were also relatively low (EIA 2017).

Gallup (2017a) also reported that, in both 2016 and 2017, a majority of Americans (59%) said “protection of the environment should be given priority, even at the risk of limiting the amount of energy supplies—such as oil, gas, and coal—which the U.S. produces.” In contrast, 34% said that the “development of U.S. energy supplies…should be given priority, even if the environment suffers to some extent.” The percentage choosing the environment over development of energy supplies was the highest it has ever been but is similar to the 58% who gave this response in 2007.

Americans also appear to support energy alternatives to fossil fuels. Gallup respondents are asked annually how they think the country should deal with “the nation’s energy problems” and then asked to choose between emphasizing production of “oil, gas and coal supplies” or “conservation by consumers.” The percentage choosing to “emphasize conservation” has risen from a low of 48% in 2011 to 61% in 2017 (Gallup 2017a). This is approaching the previous high of 64% that Gallup found in 2007. An alternative question asks respondents to choose between fossil fuel production and “the development of alternative energy such as wind and solar power.” With this question, Gallup found that 71% of Americans chose alternative energy in 2017, up from 59% in both 2012 and 2013 and similar to the high of 73% in 2016. A similar question by the Pew Research Center (2014) found that prioritizing alternative energy sources such as “wind, solar, and hydrogen” started at 63% in 2011 and then dipped to 47% in 2012 before climbing back to about 60% in late 2014 after a high of 65% in early 2014.

Alternative energy and conservation also do well when comparing questions that ask about specific energy options. In 2016, 89% of Americans told the Pew Research Center (Funk and Kennedy 2016a) that they favored “more solar panel ‘farms,’” and 83% said they would favor more “wind turbine ‘farms.’” In contrast, 43% said they would support more “offshore oil and gas drilling,” 42% said they would favor “more hydraulic fracturing…for oil and natural gas,” and 41% said they would favor “more coal mining.” The Pew Research Center (Funk and Kennedy 2016a) found, however, that there were substantial differences on views about the questions related to oil, gas, and coal by political party preference. Gallup similarly found that 35% “favor[ed]…‘fracking’” in 2017, whereas 53% opposed the technique, similar percentages to those from 2016.

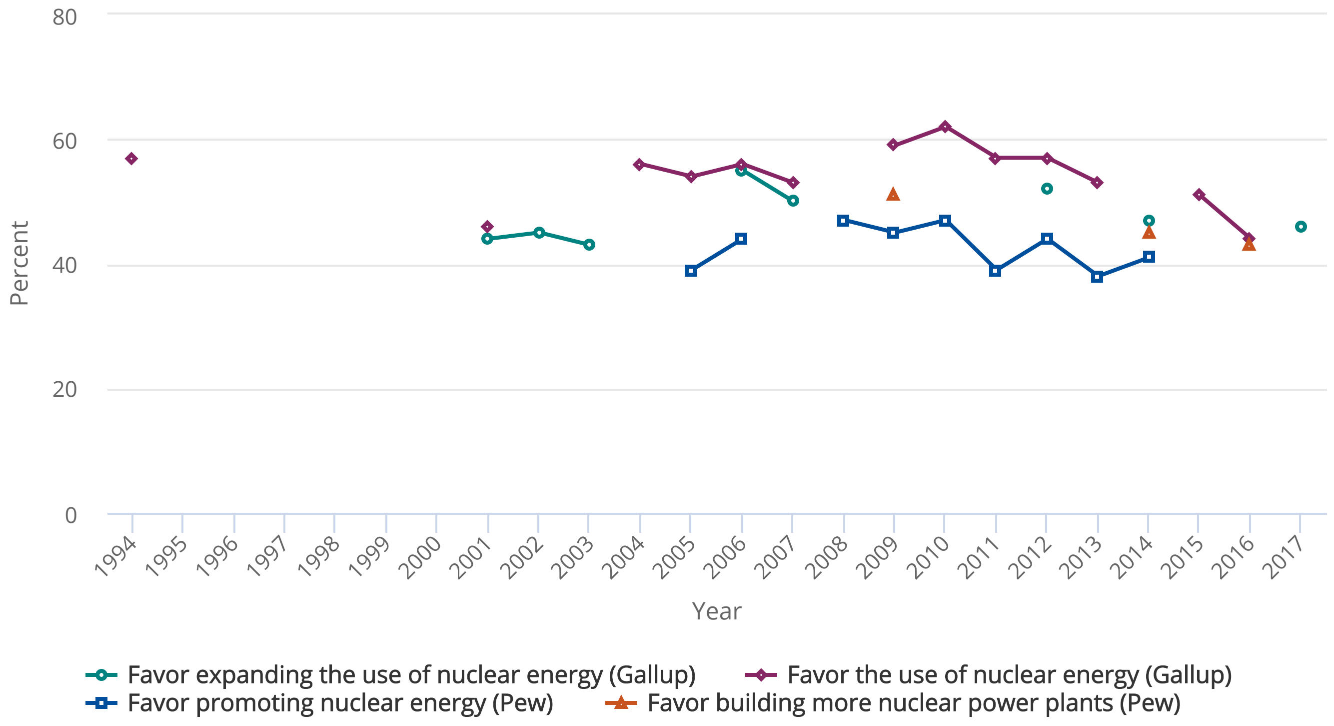
Attitudes about nuclear energy have become more negative in recent years. Support for nuclear energy likely peaked around early 2010. At that time, 62% of Americans told Gallup that they “strongly” or “somewhat” favored nuclear energy as “one of the ways to provide electricity for the United States.” In 2011, just prior to the nuclear accident in Fukushima, Japan, support had fallen to 57%. Gallup again assessed support at 57% in 2012, and support further fell to 44% by 2016 (📊 Figure

7-20) (Gallup 2017b). The fact that attitudes about nuclear energy started becoming more negative prior to Fukushima and that support did not drop substantively in the Gallup data between 2011 and 2012 led the organization to argue that "energy prices and perceived abundance of energy sources" may be behind declines in nuclear support (Riffkin 2016). It may also be relevant that worry about other environmental issues began to increase around 2010 (see the discussion above about attitudes regarding the environment).

Surveys by the Pew Research Center (2014) similarly found the start of a decline in nuclear energy support prior to the Fukushima accident (Figure 7-20). Pew pegged support for "government" policies aimed at "promoting the increased use of nuclear power" at 52% in early 2010. By mid-2010, support appeared to have fallen to the mid-40% range (e.g., 45% in October 2010). Support immediately after the 2011 Fukushima accident dipped to 39% and remained around this level through several surveys until 2014, when support was at 41%, the last time the same question was used. A second question wording used by the Pew Research Center (Funk, Rainie, and Page 2015) found that 51% of Americans said they "favor building more nuclear power plants to generate electricity" in 2009, and this percentage fell to 45% by 2014.

FIGURE 7-20

Views on nuclear energy: 1994–2017



Note(s)

Data are not available for all years. Responses to:

I am going to read some specific environmental proposals. For each one, please say whether you generally favor or oppose it. How about [e]xpanding the use of nuclear energy?

Overall, do you strongly favor, somewhat favor, somewhat oppose, or strongly oppose the use of nuclear energy as one of the ways to provide electricity for the U.S.? (Figure shows combined responses for "strongly favor" and "somewhat favor.")

As I read some possible government policies to address America's energy supply, tell me whether you would favor or oppose each. [W]ould you favor or oppose the government promoting the increased use of nuclear power? (The 2010 data point is the average of responses to four surveys conducted that year. The 2011 data point is the average of responses to two surveys conducted that year.)

Do you favor or oppose building more nuclear power plants to generate electricity?

Source(s)

Gallup, Social Series: Environment, https://www.gallup.com/file/poll/168221/Energy_I_140402.pdf, accessed 17 February 2017, Social Series: Environment, https://www.gallup.com/poll/2167/energy.aspx, accessed 17 February 2017, and Gallup Social Series: Environment, Final Topline 1–5 March 2017; Pew Research Center, *December 2014 Political Survey*, http://www.people-press.org/files/2014/12/12-18-14-Energy-topline-for-release.pdf, accessed 17 February 2017, *General Public Science Survey, August 15-25, 2014,* http://www.pewinternet.org/files/2015/07/2015-07-01_science-and-politics_TOPLINE.pdf, accessed 17 February 2017, and *Americans strongly favor expanding solar power to help address costs and environmental concerns*, http://www.pewresearch.org/fact-tank/2016/10/05/americans-strongly-favor-expanding-solar-power-to-help-address-costs-and-environmental-concerns, accessed 17 February 2017.

Science and Engineering Indicators 2018

Responses to a nuclear energy question included in the GSS are also relatively consistent with the pattern found by Gallup and the Pew Research Center. In 1993, about 40% of respondents said that they thought nuclear energy was either “extremely” or “very dangerous.” By 2016, the percentage seeing substantial danger had grown to 55%. Another 30% said nuclear energy was “somewhat dangerous,” and 13% said “not very dangerous” or “not dangerous” (Appendix Table 7-35). About 2% said they did not know how dangerous nuclear energy is. Women, younger respondents, and those with relatively high levels of science knowledge and science and mathematics education were more likely to see higher levels of danger, but the pattern is not as clear as it is with other specific attitude questions. For example, 58% of those in the lowest quartile of knowledge saw nuclear energy as “extremely dangerous” or “very dangerous,” whereas 42% of those in the top quartile held this view. Those in the second and third quartile, however, were more similar to those with less knowledge than those with the most knowledge. Similarly, for science and mathematics education, 58% of those with relatively low science and mathematics education and 59% of those with mid-level science education said they saw nuclear energy as “extremely dangerous” or “very dangerous,” whereas 44% of those with relatively high levels of science education felt this way. As noted, the percentage saying that nuclear energy is dangerous is also relatively high compared to previous years. For example, 40% said they saw nuclear energy as “extremely dangerous” or “very dangerous” in 1993, and 45% gave these responses in 2010.

International Comparisons

Europe’s 2015 Eurobarometer climate change survey (European Commission 2015) also included several questions about energy. Across European countries, between 97% (Cyprus) and 78% (Bulgaria) of residents said that it was “very important” or “fairly important” for national governments to “set targets to increase the amount of renewable energy used, such as wind or solar power, by 2030” (European Commission 2014a:55). The average across the 28 European countries surveyed was 91%. The five largest European economies were relatively similar, with Spain at 93%; Germany, the UK, and Italy at 91%; and France at 90%. The Eurobarometer report suggested that support for renewables was up slightly from 2013 but that there were few differences across demographic groups. However, those who saw climate change as a more serious problem were more likely to see renewable energy targets as important. Almost all EU respondents (92%) similarly indicated that they thought it was “very” or “fairly important” for government to provide support “for improving energy efficiency.” In China, 79% of respondents indicated that they supported funding research on “low carbon” technology (CRISP 2016). The 2014 edition of *Indicators* also reported the results of a 2010 international survey of a wide range of countries that suggested that the United States was relatively favorable toward nuclear energy when compared to the other countries surveyed (NSB 2014).

Genetically Engineered Food

U.S. Patterns and Trends

The most recent data suggest that negative views about genetically engineered (GE) food have increased in recent years in the United States. This pattern is consistent with increasing concern about various environmental issues and nuclear energy. GE food—also sometimes called genetically modified (GM) food or genetically modified organisms (GMOs)—remains an active issue for public debate around the world as new products continue to enter the market. Some scholars also point to the emergence of genetic engineering concerns as something that proponents might have limited through better communication with the public during the early research and commercialization phases (Einsiedel and Goldenberg 2006). Surveys from across many years and studies, however, suggest that many Americans question the safety of genetic engineering of food despite consensus statements from leading scientific groups. For example, the National Academies argue that there is no evidence that GM crops have caused substantial health or environmental problems since the technology emerged commercially in the 1990s (NASEM 2016b). Almost all members (88%) of the world's largest scientific society surveyed by Pew in 2015 also said they saw GM foods as "generally safe" (compared to 37% of Americans, overall) (Funk, Rainie, and Page 2015). A summary of surveys from the 1980s through 2000 (Shanahan, Scheufele, and Lee 2001) found that between one-third and one-half of Americans saw risks from genetic engineering, whereas a similar number saw benefits. This summary also found that few people felt that they knew a lot about the subject but that there was, nevertheless, broad support for labeling GE food.

GSS data suggest that concern about GE food is increasing. The percentage of Americans who said genetically modifying crops are either "extremely dangerous" or "very dangerous" has climbed from 21% in 2000 and 25% in 2010 to 43% in 2016. Another 36% said such crops were "somewhat dangerous." About 18% said they were "not very dangerous" or "not dangerous at all" (Appendix Table 7-36). Conversely, the percentage that says they see genetic modification as "not very dangerous" or "not dangerous at all" has declined from 25% in 2000 and 26% in 2010 to 18% in 2016.

There are, nevertheless, several important demographic differences in how people perceive genetic modification. For example, 53% of women said that modifying genes is "extremely dangerous" or "very dangerous," compared to 30% of men. Only those in the highest science knowledge group had meaningfully different views than those with lower knowledge. Specifically, 45% of those in the lowest quartile of science knowledge, 44% of those in the second quartile, and 47% of those in the third quartile of science knowledge indicated that they thought genetic modification was "extremely" or "very dangerous." Only 31% of those in the top quartile of science knowledge held such views. The pattern for education is similar but less pronounced. There was no meaningful variation by age.

Whereas the GSS question focuses only on danger to the environment from "crops," a 2016 survey by the Pew Research Center (Funk and Kennedy 2016b) included a battery of questions about GM foods that also showed that many Americans have concerns about the technology, even though knowledge levels likely remain low. First, about 29% of Americans said they had heard "a lot" about GM foods, 52% said they heard a little, and 19% said they had heard "nothing at all." Another question found that 6% of Americans said they cared about the issue of GM foods "a great deal," while 37% said they cared "some."

With regard to food safety, 48% of Pew Research Center (Funk and Kennedy 2016b) respondents said they thought GM foods and non-GM foods were equally healthy, and 39% said they thought GM foods were less healthy. Another 10% of respondents said they thought that food with GM ingredients is healthier than non-GM foods. About 20% of all respondents (i.e., 51%–39% who saw risks) said they thought the health risks of genetic modification were "high" or "very high." Another question found that 49% of respondents said they thought that GM foods were "very" or "fairly" likely to "lead to health problems for the population as a whole." About 49% also said that genetically modified foods will likely "create problems for the environment." On the positive side, 69% of respondents said they thought GM foods would be likely to increase the "global food supply," and 56% said they thought the technology would lead to "more affordably-priced food." As noted above in the discussion of confidence in the scientific community, 78% of Americans told the Pew Research Center (Funk and Kennedy 2016b) that they trusted scientists to “give full and accurate information about the health risks and benefits of eating genetically modified food,” the highest percentage of any other group alongside small farm owners. Previously, the Pew Research Center (Funk, Rainie, and Page 2015) had found that only 37% of Americans think that GE foods are “generally safe” to eat (compared to 57% who said it was “generally unsafe”), and only 28% think that “scientists have a clear understanding” of the “health effects of genetically modified crops.”

It is also important to consider the limitations of the available data in this area. Given low knowledge about the particular topic of GE food, other factors—such as general worldview or positive views about science and scientists (Frewer et al. 2013; McComas, Besley, and Steinhardt 2014)—may play a central role in shaping views about genetic engineering. In other words, when many respondents answer questions about genetic engineering, they are likely reporting their general views about science or nature rather than fully answering questions based on consideration of genetic engineering. The reasons for using genetic engineering may also affect whether people report favorable views. When the Pew Research Center (Funk, Rainie, and Page 2015) asked about genetic modification to “create a liquid fuel replacement for gasoline,” 68% of Americans and 78% of scientists said they would “favor” such a move.

International Comparisons

A previous analysis of worldwide views on genetic engineering concluded that respondents were more opposed to animal modification than plant modification, that Europeans saw more risks and fewer benefits than Americans or Asians, and that moral concerns are highest in the United States and Asia (Frewer et al. 2013). The 2014 version of *Indicators* also reported the results of a 2010 international survey of a wide range of countries that suggested that the United States was relatively favorable toward genetic modification compared with other countries, with only 25% of Americans saying they thought such crops should be seen as “extremely dangerous to the environment.” Several other countries, including some European countries (e.g., Belgium, Norway, Denmark), were also relatively favorable toward the technology (NSB 2014). Some of the countries in which residents were least favorable to genetic engineering included Turkey, Chile, and Russia. More recently, 59% of Chinese respondents said they thought that GM foods created an “unpredictable safety risk” (CRISP 2016).

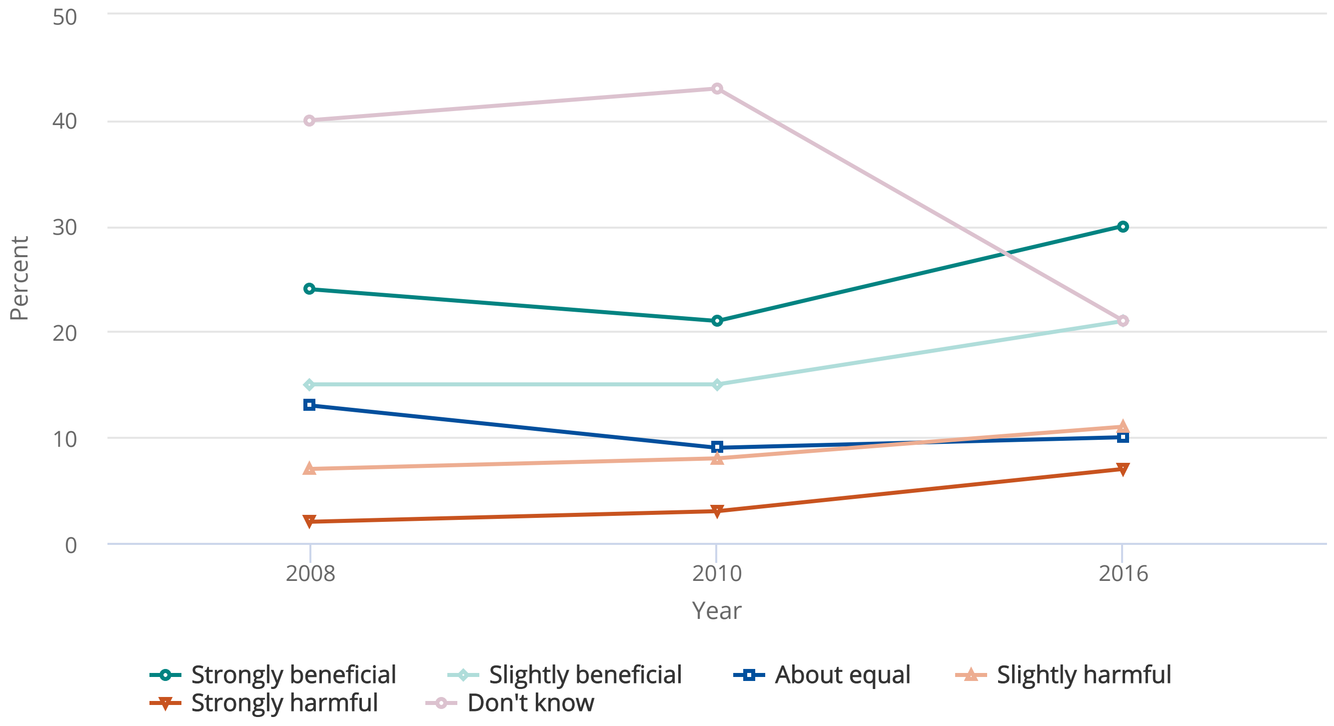
Nanotechnology

Nanotechnology involves manipulating matter at very small scales to create new or improved products that can be used in a variety of ways. Government and the private sector have made relatively large investments in this area in recent years, and innovations based on this work are now common (PEN 2015).

Recent data on public opinion about nanotechnology are limited, but the most recent GSS included a set of questions aimed at updating information previously collected by the NSF in 2006, 2008, and 2010, when there was concern that some Americans might come to see nanotechnology in the way that many people see GE food (e.g., [Einsiedel and Goldenberg 2006]). This does not appear to have happened yet. In 2016, 51% of respondents said they think that the benefits of nanotechnology will be greater than the harms (Figure 7-21; Appendix Table 7-37). This includes 30% who say they expect strong benefits and 21% who expect slight benefits. Another 18% said that they thought the “harmful results” would be greater, including 7% who expect strong harms and 11% who expect slight harms. About 10% volunteered that the benefits and harms would be about equal, and 21% volunteered that they did not know whether benefits or harms were more likely. In other words, these individuals asked to have their views recorded as seeing the benefits and harms as about equal or insisted they could not choose between benefits and harms, even though the survey questionnaire did not provide this option.

FIGURE 7-21

Views on nanotechnology: 2008, 2010, 2016



Note(s)

Responses to the two-tiered question *Nanotechnology works at the molecular level atom by atom to build new structures, materials, and machines. People have frequently noted that new technologies have produced both benefits and harmful results. Do you think the benefits of nanotechnology will outweigh the harmful results or the harmful results will outweigh the benefits?* and *Would you say that the balance will be strongly in favor of the benefits/harmful results, or only slightly?* Percentages may not add to 100% because of rounding.

Source(s)

NORC at the University of Chicago, General Social Survey (2008–16).

Science and Engineering Indicators 2018

The percentage saying they do not know whether nanotechnology is likely to produce harms or benefits rose from 2006 to 2010 but dropped in 2016 (Appendix Table 7-37). In 2006, 32% of respondents gave a “don’t know” response, 40% gave this response in 2008, and 43% gave this response in 2010 but then only 21% said they did not know in 2016 (Appendix Table 7-37). Of those who expressed an opinion, the percentage of people saying they expect benefits from nanotechnology has been fairly stable, with 64% in 2016, 65% in 2010, 64% in 2008, and 59% in 2006. The percentage who expect harms among those who expressed an opinion, however, has also climbed from 13% in 2006 to 23% in 2016. This is possible because the proportion volunteering that they expect about equal benefits and harms has fallen from 28% of those who expressed an opinion in 2006 to 13% in 2016. This increase in uncertainty and concern seems broadly consistent with increased concern about the environment, nuclear energy, and GM foods.

Men, younger respondents, those with more education, and those with higher levels of income were more likely to report that they expected nanotechnology benefits. For example, in 2016, 61% of men said they expected benefits, while only 41% of women gave this response (Appendix Table 7-37). About the same number of men (10%) and women (11%) said they thought the benefits and harms would be equal, and similar proportions (16% of men and 19% of women) said they expected harms. However, about 12% of men said they did not know whether harm was more likely than benefits, but 29% of women said they did not know.

As with the data on GE food, it is important to recognize that people's low levels of knowledge about nanotechnology may mean that they are largely responding to questions about the issue based on such factors as their overall trust in science or their worldview. Additional factors such as the content or wording of the questions or the context of the survey may contribute to such processes.

Stem Cell Research and Cloning

U.S. Patterns and Trends

Stem cell and cloning research focus on understanding how to use biological material to produce living cells, tissues, and organisms. Such research creates opportunities for enhanced understanding of life and opportunities to develop new health care treatments. The intersection of health, human life, and the destruction of human embryos, however, raises ethical issues that have spurred public debate.

Most Americans appear to support the use of embryonic stem cells for medical research. Annual Gallup data showed that, in 2016, 60% of Americans saw using stem cells from human embryos in medical research as "morally acceptable" (Jones and Saad 2016; Swift 2016). The percentage of those who saw such research as morally acceptable is down 4 percentage points from 2015, but over the last 10 years the percentage of respondents saying such research was morally acceptable has fluctuated between a high of 65% in 2014 and a low of 57% in 2009. The lowest level of perceived moral acceptability was 52% in 2002, the first year for which Gallup has data.

Gallup also asks about the morality of human and animal cloning. In 2016, 13% of Americans said that it was morally acceptable to clone humans, and 34% said it was morally acceptable to clone animals (Jones and Saad 2016; Swift 2016). The percentage saying that cloning animals is acceptable has stayed relatively stable—between 29% and 36%—since 2001, when Gallup first asked about the subject. The percentage saying that it is morally acceptable to clone humans hit a high of 15% in 2015 and increased from a low of 7% since Gallup first asked about the subject in 2001.

International Comparisons

The last time a large sample of Europeans was asked about cloning was in 2010, when a Eurobarometer survey found that 63% of respondents across 27 European countries supported the use of stem cells from human embryos, either with no special laws (12%) or "as long as this is regulated by strict laws" (51%). The use of adult stem cells, in contrast, was supported by 69% of Europeans, including 15% who saw no need for special laws and 54% who would approve if use was regulated by strict laws (European Commission 2010b).

Animal Research

U.S. Patterns and Trends

The medical research community conducts experiments on animals for many purposes, including testing the effectiveness of drugs and procedures that may eventually be used to improve human health and advance scientific understanding of biological processes.

Most Americans support at least some kinds of animal research, but this support has fallen in recent years. According to Gallup, about 53% of Americans in 2016 said they saw “medical testing on animals” as “morally acceptable” (Jones and Saad 2016; Swift 2016). This is the lowest it has been and is down from 65% in 2001, when Gallup first asked the question. A different question by the Pew Research Center (Funk, Rainie, and Page 2015) found that, in 2014, 47% of Americans said they “favor” “the use of animals in scientific research,” down from 52% in 2009.

International Comparisons

The most recent similar data from Europe are from a 2010 survey showing that, on average, Europeans oppose animal testing, but these views vary widely. Respondents were asked whether “scientists should be allowed to experiment on animals like dogs and monkeys if this can help sort out human health problems.” About 44% of Europeans said they “totally agree” or “tend to agree” that such experiments should be allowed, whereas 37% said they “totally disagree” or “tend to disagree” (European Commission 2010a).

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[1] There is some evidence from a large-scale experimental study that the wording used in such questions (“global warming” or “climate change”) can have an effect on reported beliefs about global climate change (Schuldt, Konrath, and Schwarz 2011). Other studies, however, suggested that such wording differences have limited effect (Dunlap 2014; European Commission 2008; Villar and Krosnick 2010).

Conclusion

Overall, the survey results presented here continue to indicate that interest in, general knowledge of, and general attitudes about S&T remain relatively positive and stable in the United States. As in previous years, Americans express relatively high levels of interest in various S&T issues, with the one change being that they continue to shift their focus toward getting that information online. The results also show that many Americans know basic facts about science, although many still get the NSF trend questions wrong. For attitudes, a substantial majority of Americans continue to see substantially more benefits than harms from science, have relatively high levels of confidence in the scientific community, and would like to see science supported.

However, whereas interest, knowledge, and general S&T attitudes may be stable, indicators of attitudes about specific S&T issues—including environmental, energy, and emerging technologies—suggest that many Americans are increasingly concerned about pollution and new technologies. The fact that the available indicators for different environmental issues have moved together suggest a common source of concern. There also remain, however, many Americans who see the opportunity for substantial continued progress through S&T or who have relatively low environmental concern. Overall, the majority of Americans appear concerned about the state of the environment and the degree to which advanced technology areas, such as nuclear energy, genetic engineering, and nanotechnology, may create new dangers and yet remain generally supportive of S&T and scientists. Further, while there are limited data, it appears that Americans tend to have lower average levels of concern about S&T issues, and higher average levels of optimism, than the populations of other countries.

In reviewing this chapter, it is important to recall that the purpose of the types of indicators described here is to allow a data- and evidence-based discussion about what Americans think and know about topics related to science, technology, and engineering. The emphasis on between-group comparisons, over-time comparisons, and between-country comparisons is not to rank groups or countries but to provide the type of context that allows a discussion about the nature of the global landscape within which the United States operates. Such comparisons can tell us where the United States may have had success and where there might be potential for improvement. For example, the fact that Americans appear to visit more S&T museums and centers than residents of many other countries might suggest an area of strength on which we might build. As an *Indicators* chapter, the current report, however, highlights the nature of and trends in public views without assessing why changes may have occurred. This leaves to others the challenge of determining the causes of the patterns and trends described. Some of this literature is cited here, but the work of better understanding public attitudes and knowledge about science is ongoing.

Further, in reading the chapter, it is important to consider the overall mosaic that can be assembled from all of these indicators and to avoid putting too much emphasis on any specific statistic. Survey data are powerful tools for understanding the world but, as with all surveys, the indicators discussed are subject to random variation, and it is therefore important to analyze long-term trends and multiple related questions before drawing strong conclusions. Another ongoing limitation of the available indicators is that many of the international comparison data come from Europe, with only limited recent data from the Asia-Pacific region, where there is a high level of S&T activity. Data from Africa and South America are even scarcer. Similarly, the questions asked vary by country in small and large ways. As such, international comparisons should be made with caution, and thoughtful consideration should be given to what we may know and what we do not know.

Despite such concerns, one pattern in the surveys reviewed continues to stand out. The data show quite consistently that Americans who have had more exposure to S&T—including those who are college educated and have completed college courses in science and mathematics—tend to understand more about S&T, see S&T in a more positive light, and engage with S&T more often. Although it is not clear whether these associations are causal, the pattern underscores the potential role of formal science, technology, engineering, and mathematics (STEM) education in shaping how people think about S&T. It is also important, however, to recognize that Americans interact with science beyond formal education systems through channels such as museums, a range of media (television, websites), and daily interactions with others in their personal or professional lives. Data on these types of exposure pathways are not generally as available as data related to formal education.

Those who would seek to change knowledge and attitudes about S&T now have a wide range of formal and informal channels through which to reach Americans. Attracting young people to S&T professions and cultivating positive attitudes about the value of S&T will be important for the United States to remain a world leader in S&T. Efforts to engage with the public on such matters are occurring through a range of online tools and community locations (e.g., schools, museums, festivals, restaurants), workplaces, and homes. The challenge for those who see progress on S&T as important to economic and social development is to ensure that the members of the S&T community engage their fellow citizens actively, openly, and respectfully in the best traditions of science.

Glossary

Definitions

Biotechnology: The use of living things to make products.

Climate change: Any distinct change in measures of climate lasting for a long period of time. Climate change means major changes in temperature, rainfall, snow, or wind patterns lasting for decades or longer. Climate change may result from natural factors or human activities. Global warming is often the focus of climate change discussion.

Cloning: Reproductive cloning involves using technology to generate genetically identical individuals with the same nuclear DNA as another individual. Therapeutic cloning involves medical research to develop new treatments for diseases.

European Commission: The governance body for the European Union (EU) that is responsible for the Eurobarometer series of surveys. As of February 2017, the EU comprised 28 member nations: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, and the United Kingdom. Unless otherwise noted, data on the EU include all of these 28 members. In this regard, Eurobarometer data from earlier years often do not include recently added members.

Genetically engineered (GE) food: A food product containing some quantity of any GE organism as an ingredient. Also sometimes called genetically modified (GM) food, genetically modified organisms (GMOs), or agricultural biotechnology.

Global warming: An average increase in temperatures near the Earth's surface and in the lowest layer of the atmosphere. Increases in temperatures in the Earth's atmosphere can contribute to changes in global climate patterns. Global warming can be considered part of climate change along with changes in precipitation, sea level, and so forth.

Nanotechnology: Manipulating matter at unprecedentedly small scales to create new or improved products that can be used in a wide variety of ways.

Key to Acronyms and Abbreviations

EU: European Union

GE: genetically engineered

GM: genetically modified

GMO: genetically modified organism

GMU: George Mason University

GSS: General Social Survey

NSF: National Science Foundation

R&D: research and development

S&E: science and engineering

S&T: science and technology

STEM: science, technology, engineering, and mathematics

UK: United Kingdom

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CHAPTER 8

Invention, Knowledge Transfer, and Innovation

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Highlights

Innovation Occurs in an Interconnected System with S&E as a Key Component

The S&E workforce and R&D activity increase the capital stock of knowledge—either through fundamental scientific advances or by extending basic knowledge for practical applications. This knowledge storehouse, in turn, serves as a key resource for those who invent and innovate. Intertwined economic and organizational processes link knowledge advances to invention, knowledge transfer, and innovation.

- The S&E-trained workforce conducts research to make discoveries and create new technologies.
- Businesses, universities, federal laboratories and research centers, and nonprofit institutions all contribute to discoveries.
- Production and trade in knowledge-intensive goods and services fuel the transfer of S&E into commercial applications.
- The theory and data available advance our understanding of the innovation system and its important dynamics. However, metrics to gauge performance and effectiveness are incomplete, particularly for outcomes and impacts.

Inventions and the Rate of Their Discovery Are Essential Features of a National Innovation System

An invention brings something new into being and has a practical bent—the production of a new product or process that is potentially useful, previously unknown, and nonobvious. Patent data, valuable for their technological and geographic detail, are indicators of invention, rather than innovation.

The number of patents from the U.S. Patent and Trademark Office (USPTO) granted to U.S. inventors continues to grow, although at a slower rate than was seen earlier in the decade. The most well-defined metrics on U.S. inventions are patent applications and awards and the invention disclosures reported by the technology transfer offices at academic institutions and at the nation's federal laboratories. Comprehensive patent data have become increasingly available and extensively analyzed in recent years. Invention disclosures are accessible in regular reports. Nonetheless, both these sets of data provide only a partial picture of U.S. invention.

- Foreign owners account for more than half of USPTO patents in recent years, almost 152,000 out of a total of more than 300,000 in 2016.
- The number of U.S. university patents granted by USPTO continues to increase rapidly, more than doubling between 2008 and 2016, reaching more than 6,600 in 2016.
- The number of foreign university patents granted by USPTO more than quadrupled during this same period, reaching more than 4,200 in 2016.
- Inventors in the United States received nearly half of USPTO patents granted in 2016. Japan and the European Union (EU) were the second and third largest recipients.
    - The share of USPTO patents granted to U.S. inventors declined from 51% in 2006 to 47% in 2016.

    - Faster growth in the number of USPTO patents granted to non-U.S. inventors was led by South Korea, China, and India over the same period.
- USPTO patents by U.S. inventors are relatively more concentrated in six advanced and science-based technologies, including three in the chemistry and health category—medical technology, pharmaceuticals, and biotechnology.
- USPTO patents by EU inventors are concentrated in nine technologies that are closely related to chemistry and health, including pharmaceuticals and biotechnology.
- Japan's USPTO patents are relatively more concentrated in two information and communications technologies—semiconductors and telecommunications—and in optics, surface technology and coating, and materials and metallurgy.

Knowledge Transfer Is an Essential Capacity of the National Innovation System

Technology transfer is "the process by which technology or knowledge developed in one place or for one purpose is applied and used in another place for the same or different purpose." Scientific discoveries and inventions flow into economic activity through freely accessible dissemination (e.g., open scientific and technical literature, person-to-person exchanges) and market-based transactions (e.g., patent licensing, formal collaborative R&D relationships that provide intellectual property protections, use of copyrighted materials). Organizations in academia, government, business, and nonprofit sectors all have policies and activities directed at identifying new knowledge and technology and helping transfer them where they can be applied, further developed, and eventually commercialized as new products and processes.

The federal government has been particularly active since the early 1980s in establishing policies and programs to improve the transfer and economic exploitation of the results of federally funded R&D—particularly through the Bayh–Dole Act of 1980 (affecting federally funded R&D in academia) and the Stevenson-Wydler Technology Innovation Act of 1980 and subsequent amplifying legislation (promoting technology transfer activities by the nation's federal laboratories). Most statistics on technology transfer concern these federal government technology transfer policies, as they operate through U.S. higher education institutions and U.S. federal laboratories. Less is known about the technology transfer that happens within the private or nonprofit sectors.

- In the higher education sector, invention disclosures filed through university technology management and transfer offices totaled 22,507 in 2015, up from 13,718 in 2003.
- University applications for U.S. patents also increased over time: 13,389 in 2015, nearly doubling from 7,203 in 2003.
- The number of U.S. patents awarded to universities remained flat between 2003 and 2009, and then rose to 6,164 in 2015.
- Active licenses that generated revenue from university inventions increased from 18,845 in 2001 to 40,402 in 2015.
- Business startups from university technology transfer reached 950 in 2015, with the number of past startups still operating that year at 4,757.
- For the U.S. federal laboratories (including federal agency intramural R&D facilities and federally funded research and development centers), invention disclosures totaled 5,103 in 2014, compared with 5,106 in 2003. Other trends in U.S. federal laboratories included the following.
    - A total of 2,609 patent applications were filed in 2014, compared with 2,318 in 2003.

  - The number of patents issued was 1,931 in 2014, compared with 1,631 in 2003.
  - The total of active invention licenses (mainly of patents) across all the federal laboratories was 3,956 in 2014, compared with 3,747 in 2003.
  - Active licenses for other intellectual property (i.e., other than patents, including copyrights) totaled 16,866 in 2014, compared with 2,771 in 2003.

- Cooperative R&D agreements (CRADAs) between federal laboratories and nonfederal partners (e.g., with businesses, nonprofit organizations, and other nonfederal organizations) totaled 9,180 in 2014, up from 5,603 in 2003. Other types of collaborative R&D relationships (the authorities for which vary by the agencies; e.g., relationships through the National Aeronautics and Space Act of 1958) totaled 27,182 in 2014, compared with 8,162 in 2003.
- Most of the federal agencies engage in all these technology transfer mechanisms, although the emphases vary. Some are particularly intensive in patenting and licensing activities; others are intensive in transfer through collaborative R&D relationships.
- Some agencies have unique transfer authorities (statutory) that can confer practical advantages (e.g., the National Aeronautics and Space Administration [NASA] through the National Aeronautics and Space Act of 1958; the U.S. Department of Agriculture [USDA], with a variety of non-CRADA mechanisms for cooperative R&D; the Department of Energy [DOE], whose contractor-operated laboratories and nonfederal staff can use copyrights to protect and transfer computer software).
- The federal agencies accounting for the largest portion of federal R&D—including USDA, the Department of Commerce (DOC), the Department of Defense (DOD), the Department of Homeland Security (DHS), the U.S. Department of Health and Human Services (HHS), and NASA—account for most of the technology transfer activities enabled by the Stevenson-Wydler Act.
- U.S. business sector–based researchers produced more than 50,000 peer-reviewed publications in 2016. Almost half were coauthored with university researchers, and 12% were coauthored with federal agency researchers.
- Technology licensing and other global exports of intellectual property in trade flows were $272 billion in 2016. Together, the United States, Japan, and the EU account for more than 80% of this total.

Venture Capital Investment Supports the Commercialization of Emerging Technologies

Access to financing is an essential component of the translation of inventions to innovations, both for new and growing firms. The difficulty of entrepreneurs obtaining financing contributes to the "valley of death," the inability of new and nascent firms to obtain financing to commercialize their inventions and technology. Venture capital investment also supports product development and marketing, company expansion, and acquisition financing.

- Venture capital investment, an indicator of support for the commercialization of emerging technologies, was more than $130 billion globally in 2016.
- The United States attracts slightly more than half of this venture capital funding. Four industries—software as a service, mobile, life sciences, and e-commerce—received the largest amount of U.S. venture capital investment between 2011 and 2016.
- China is the second largest recipient, attracting about one-quarter of the venture capital funding. Venture capital investment in China soared from $3 billion in 2013 to $34 billion in 2016, the fastest increase of any economy.

Federal Policies and Programs Have Been Implemented over the Past Several Decades to Reduce Characteristic Barriers to Innovation

In response to ongoing national concerns about the comparative strength of U.S. industries and their ability to succeed in the increasingly competitive global economy, the federal government has been active since the late 1970s in establishing policies and programs directed at strengthening the prospects for the development and flow of early-stage technologies into the commercial marketplace, particularly where the R&D has been federally funded.

- Federal funding to small entrepreneurial companies engaged in R&D with eventual commercialization objectives, through the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs, are now considerably larger than when these programs were first initiated in, respectively, the early 1980s and the mid-1990s.
- At its start in FY 1983, the SBIR program (across all participating agencies) made 789 awards (all Phase I) for a total of $38 million in funding; in FY 2015, 4,508 awards were made (Phase I and Phase II), with funding totaling $1.923 billion.
- The STTR program started in FY 1995, with a single Phase I award for $100,000. In FY 2015, 725 STTR awards were made (Phase I and Phase II), with funding totaling $258 million.
- Beyond the well-known SBIR and STTR programs, which apply across much of the federal government, some departments or agencies have their own early-stage development programs more narrowly directed at their mission objectives. Examples of these programs are the DOC National Institute for Standards and Technology's (NIST's) Hollings Manufacturing Extension Partnership, DOE's Advanced Research Projects Agency—Energy, and the National Science Foundation's (NSF's) Industry–University Cooperative Research Centers Program (IUCRC). (An appendix table to the chapter identifies a larger set of these programs across the USDA, DOC, DOD, DOE, HHS, DHS, Department of Transportation, Environmental Protection Agency, NASA, and NSF.)

Innovation Takes Place in Manufacturing, Services, and Other Industries

Indicators of innovation in firms—the implementation of a new or significantly improved product or business process—show that information and communications technology (ICT)-producing industries report many of the highest rates of innovation. These indicators are collected in survey data guided by The *Oslo Manual* of the Organisation for Economic Co-operation and Development (OECD) and Eurostat (2005).

- One in six U.S. firms (17%) introduced a new or significantly improved product or process between 2013 and 2015, according to the Business R&D and Innovation Survey (BRDIS).
    - U.S. manufacturing industries see highest rates of innovation in computer and electronic products (57%) and electrical equipment and components (48%).
    - U.S. nonmanufacturing industries see highest rates of innovation in computer systems design (44%), scientific R&D services (44%), electronic shopping and auctions (40%), and information (31%).

Economic Impacts of Innovation Are Indirectly Measured, and Show Slowing Growth

Impacts of innovation are understood in multiple ways, and economic indicators are a partial but quantifiable measure. Multifactor productivity, the output growth that cannot be attributed to labor and capital inputs, is a broad measure of

the impact of innovation and technological change on the economy. It shows declining growth in the United States compared with the 2000s and earlier decades. This is true for the United States and for many other economies. Small, fast-growing firms in the United States, which are a measure of entrepreneurship and its associated job growth, have shown a declining rate of new firm formation since the early 2000s.

Introduction

Invention, knowledge transfer, and innovation are distinct but interrelated components of a complex system for transforming creativity and knowledge from S&E into benefits to society and the economy. Scientific discovery, as extended and amplified by applied research and development, increases the storehouse of knowledge available for further transformation. Invention and innovation draw from this resource.

A complete picture of the innovation process is multidimensional. It requires indicators on actors, as individuals and through institutions that include businesses, government, academia, and nonprofit institutions. Inputs to innovation also include physical capital and infrastructure, both public and private, intangible capital, and publicly available knowledge. Innovation incidence provides an indicator of commercialization through the business sector. Beyond incidence, indicators of the impact of innovation presented here focus on two economic impacts, productivity growth and firm growth.

Chapter Overview

Invention brings something new into being and has a practical bent—the production of a new process or product that is potentially useful, previously unknown, and nonobvious. Invention contrasts with the focus of scientific research that leads to *discovery*—knowledge about existing phenomena that previously were unknown. In practice, inventions and scientific discovery often interact with each other: solving a practical problem may require the application of basic science not yet discovered, whereas scientific discovery may yield unanticipated applications that lead to potentially useful products and processes. In this chapter, we present data on inventions as represented by patents, along with information about their sources. See sidebar Key Terminology for descriptions of key terms used in this chapter.

SIDEBAR

Key Terminology

Invention: The development of something new that has a practical bent—potentially useful, previously unknown, and nonobvious.

U.S. Patent and Trademark Office (USPTO) patent: A property right granted by the U.S. government to an inventor "to exclude others from making, using, offering for sale, or selling the invention throughout the United States or importing the invention into the United States" for a limited time in exchange for public disclosure of the invention when the patent is granted.*

Knowledge transfer: The process by which technology or knowledge developed in one place or for one purpose is applied in another place for the same or a different purpose. This transfer can occur freely or through exchange, and deliberately or unintentionally.

Innovation: The implementation of a new or significantly improved product (good or service) or process, a new marketing method, or a new organizational method in business practices, workplace organizations, or external relations. External relations include collaborations with other institutions, including customers, and first-time outsourcing or subcontracting (Organisation for Economic Co-operation and Development [OECD] 2005).

Innovation activities: All scientific, technological, organizational, financial, and commercial steps that actually lead, or are intended to lead, to the implementation of innovations. These steps include R&D, acquisition of external knowledge and capital equipment, market preparation, development of new organizational methods, and design activities (OECD 2005).

Economic impacts of innovation: The effects of innovations and innovation activities on business activities, economic output, employment, and standard of living.

* This is the USPTO definition, found on the USPTO website at https://www.uspto.gov/learning-and-resources/glossary#sec-p, accessed 15 June 2017.

The transition from potential to realized usefulness for discoveries and inventions generally involves other actors besides scientists, engineers, and inventors. The discoveries and inventions must somehow be envisioned as useful and then adapted and adopted into practice and into circulation in the economy. This process frequently involves the transfer of science and technology (S&T) to businesses, government entities, universities, other organizations, and individuals for further development and eventual commercial and otherwise useful applications. Indicators for these activities include licensed inventions, citations, cooperative agreements, and collaborations. Other aspects of this transfer take place directly between individuals as they interact at work and less formally. Although harder to identify, this less formal or tacit transfer of technical knowledge is also an important dimension.

The creation of new products and processes through innovation is a key goal for many nations. According to the Organisation for Economic Co-operation and Development (OECD), common policy objectives for innovation include sustainable economic growth; good-quality jobs; an increased standard of living, and addressing key health, environmental, and social challenges (OECD 2014, 2016). Many countries envision enhancing firm-based innovation and entrepreneurship as key paths toward those goals. These paths intersect as entrepreneurs start new firms that create new products and introduce new processes. Although different stakeholders emphasize different aspects of innovation, there has been broad consensus that S&T policy and economic policy at the national level should encourage and support innovation, with economic growth and advancements in knowledge as important justifications for increased investment in S&T.

The longer-term impacts of the innovation process are often the ultimate targets of interest. These impacts emerge as knowledge, inventions, and innovations diffuse through society. They include those that are desired, such as sustainable economic growth, good-quality jobs, an increased standard of living, environmental quality, and addressing broader societal challenges. The innovation process has the potential for other, and less desirable, outcomes as well. The latter may include rapid obsolescence of some job skills, increased inequality across regions and groups of people, the vulnerability of systems to attacks, and ethical issues raised by new technologies.

Identifying when innovation has taken place and its impacts presents measurement challenges; these challenges are present in other hard-to-measure outputs, such as those that result from public and private spending on health care or education.[1] While business surveys provide indicators of product and process innovation for many firms, the data as yet present an incomplete picture of innovation output and its economic impact. The result is frequent use of innovation-related inputs, such as employment of scientists and engineers, or innovation-related activities, such as R&D and patenting, as indicators of innovation.

A quantifiable and comparable economic impact metric for innovation is multifactor productivity (MFP). MFP is an economic efficiency measure calculated as the output growth that cannot be attributed to labor and capital inputs, after accounting for changes in workforce skill and the quality of capital. Estimated from national economic accounts data, it is an indicator of overall technological change in a sector or economy. However, MFP is also affected by the timing between innovation and its widespread adoption, complicating inferences about the pace of innovation.

This measurement challenge, along with the breadth of policy interest in innovation and the factors that influence it, shapes the choice of indicators presented in this chapter. For each of the three topics covered in this chapter, invention, knowledge transfer, and innovation, the section includes a brief discussion of the gap between the data available and the indicator desired.

The innovation-related data in this chapter complement the data on human capital and market activity presented in previous chapters in this report. The chapters of *Science and Engineering Indicators 2018* touch on many topics that feed into this system, such as the S&E workforce, the role of universities, and R&D activity. In this system human, physical, and intangible capital interact through activities that include R&D, invention, and production.

The outputs from these activities can be knowledge capital, inventions, publications, or research tools, or new products, services, or ways of doing business. The systems framework for studying innovation recognizes that there may be significant feedback mechanisms, often complex and numerous, and such mechanisms magnify the ultimate impact of innovation activities. Scientific discoveries and inventions can be used repeatedly, and scientists and engineers add to their human capital through their discoveries. As knowledge and human capital accumulate and are widely used, many new discoveries and innovations build on those that came before.

These activities take place in a complex environment that includes the availability of financing for innovation, public infrastructure, the tax and regulatory environment, intellectual property protection, social attitudes toward risk, and relationships across institutions.

Chapter Organization

This chapter is organized into three principal sections on the following discussion topics. Invention is discussed in the first section, and patenting data are shown for the U.S. Patent and Trademark Office (USPTO) by sector and by technology area. The knowledge transfer section of the chapter provides data on technology transfer activities of academic institutions and the federal government, invention disclosures, patenting, licensing, and collaborative R&D agreements. Data are presented on citations within patent documents to peer-reviewed literature and to coauthorships between businesses and authors from other sectors. For greater detail on bibliometric indicators, see Chapter 5 section Outputs of S&E Research: Publications. The final section, on innovation, provides data on venture capital funding, government policies and programs to encourage early-stage development, survey-based indicators of innovation incidence in business, and measures of the economic impact of innovation—productivity and trends in the number and employment effects of small and fast-growing firms.

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[1] Although indicators are always partial measures of the concepts in which we are interested, this is particularly true with innovation. The output can be intangible and often unique, and although products created by innovation are produced and sold in the market, process and organizational innovations are hard to identify and to distinguish from trivial improvement.

Invention: United States and Comparative Global Trends

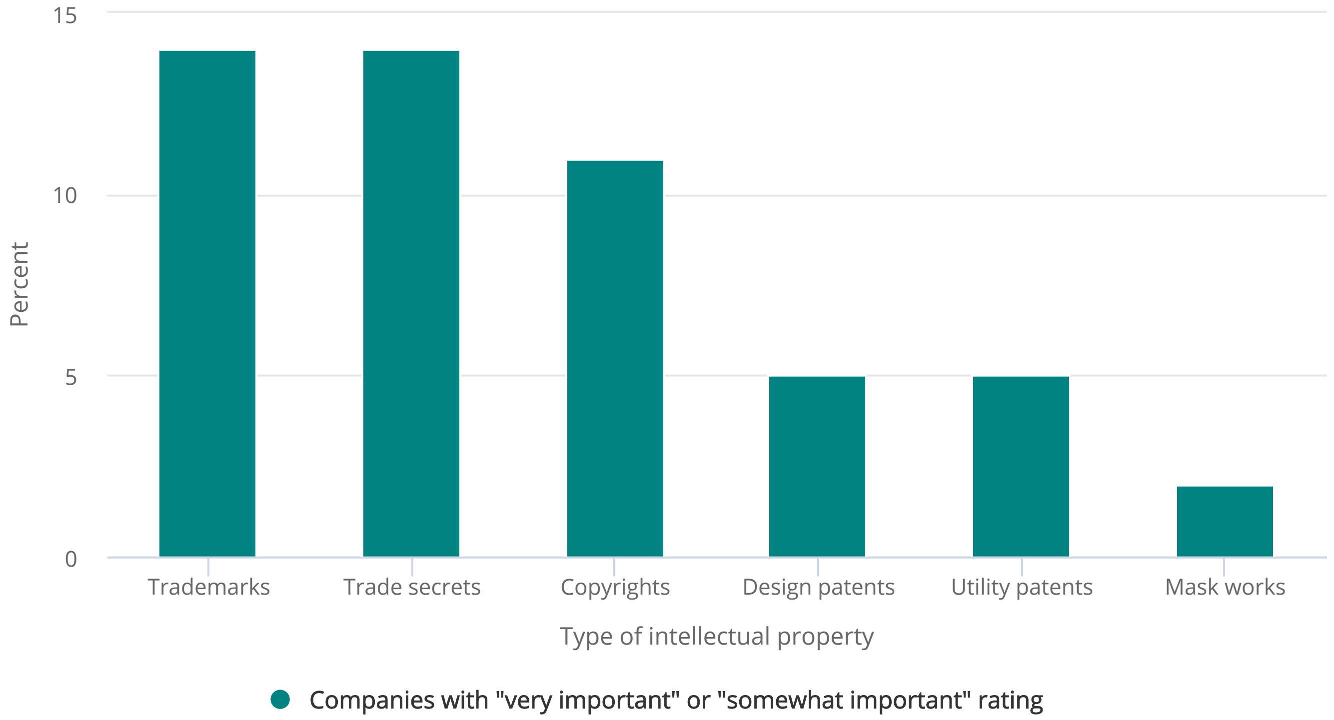
Inventions and the pace of their emergence are critical features of a national innovation system. Invention is the creation of new, useful, and nonobvious goods, services, and processes and is an important source of the innovations that eventually emerge in the marketplace or other practical use. Some of these may be described in scientific papers, which provide a means for researchers to claim credit and disseminate the results of their discoveries.

Patents serve a different purpose. Inventors often have economic motivations to keep the details of their inventions secret. The patenting system provides the legal right for a limited time to exclude others from making, using, offering for sale, or selling the invention, in exchange for public disclosure of the technical information in the granted patent. Extensive publicly available administrative data exist for patents and their inventors, and extensive databases allow for systematic insights into these patents. In the absence of other comprehensive data on invention, patent data provide unique and useful insights into the inventions deemed valuable enough to patent. However, analysis of these data requires caution.

One caveat is that most patented inventions are never commercialized; they are neither representative of all inventions nor are they measures of innovation. Many valuable inventions that are commercialized are not patented. Companies choose a variety of strategies to protect their inventions and intellectual property. For example, U.S. companies rate trade secrets higher than patents in their importance for protecting intellectual property (Figure 8-1), which is true even for R&D-performing firms.[1]

FIGURE 8-1

For companies that performed or funded R&D, shares rating intellectual property as being very or somewhat important: 2011



Note(s)

A mask work is a two- or three-dimensional layout or topography of an integrated circuit on a semiconductor that is protected under U.S. intellectual property law.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Business R&D and Innovation Survey (BRDIS), 2011.

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In addition, patent protection may be sought for reasons other than intended commercialization. Privately owned patents may be obtained to block rivals and negotiate with competitors, to use in lawsuits, or to build “thickets” of patents to impede or raise others’ costs of R&D and innovation (Cohen et al. 2000). Research suggests that some organizations and countries pursue “strategic patenting” to block competitors and to monetize patents through licensing and other activities (Ernst 2013:1–9). Other firms may respond by patenting defensively. New and emerging firms may seek patent protection to help obtain financing because investors perceive patents as potentially valuable for a firm’s assets and future profitability. Finally, cross-country analysis indicates that international differences in taxes on corporate and patent income influence the choice of patent location for multinational firms (OECD 2016:3). However, within these limitations, USPTO patent documents tell us when and in what technology areas inventors have decided to protect their intellectual property with patent protection. This rich detail, which also includes the name and address of the inventor and assignee, justifies their presentation. U.S. patents are issued to provide protection to inventions in the U.S. market. Foreign owners account for more than half of USPTO patents in recent years, 152,000 out of a total of slightly more than 300,000 patents granted in 2016 (Appendix Table 8-1). The USPTO reports the five organizations awarding the highest numbers of patents in 2015 as IBM, Samsung, Canon, Qualcomm, and Google (USPTO 2017).

USPTO Patenting Activity

As described previously, the purpose of patenting is to allow inventors to gain the economic benefits of their inventions in exchange for disclosure of technical information about the invention. Most patenting takes place in the business sector. Motivations differ substantially from the motivation of authors of peer-reviewed literature, where original contributions to publicly available knowledge may benefit reputation and career advancement without a direct financial benefit for the authors. Business researchers are also more likely to be engaged in experimental development activity than their academic and government counterparts (see Table 4-4 in Chapter 4), suggesting more opportunities for direct commercial applications of their work.

USPTO patents provide data on the inventor and the owner of the patent (known as the assignee). The data described in the next several paragraphs are based on the economic sector of the patent owner. In 2016, 151,000 USPTO patents were assigned to U.S. owners (Appendix Table 8-1). Among these U.S. owners, the private sector (for-profit companies) by far receives the most patents (85% share). Individuals receive the next largest share (9%), followed by the academic sector (4%). The government sector receives a small share of patents (1%), reflecting in part the focus of government entities on activities other than the protection of intellectual property, as well as a small number of U.S. government patents whose contents may reveal sensitive security information. The nonprofit sector, which is included in the "other" category, receives a very small share of patents (0.3% or less). Over the last decade, the private sector's share of U.S. patents slightly increased from 82% to 85%. Although the individual share declined from 13% to 9%, continuing a long-term trend away from individual patenting, almost 13,600 patents were granted to individual U.S. owners in 2016.

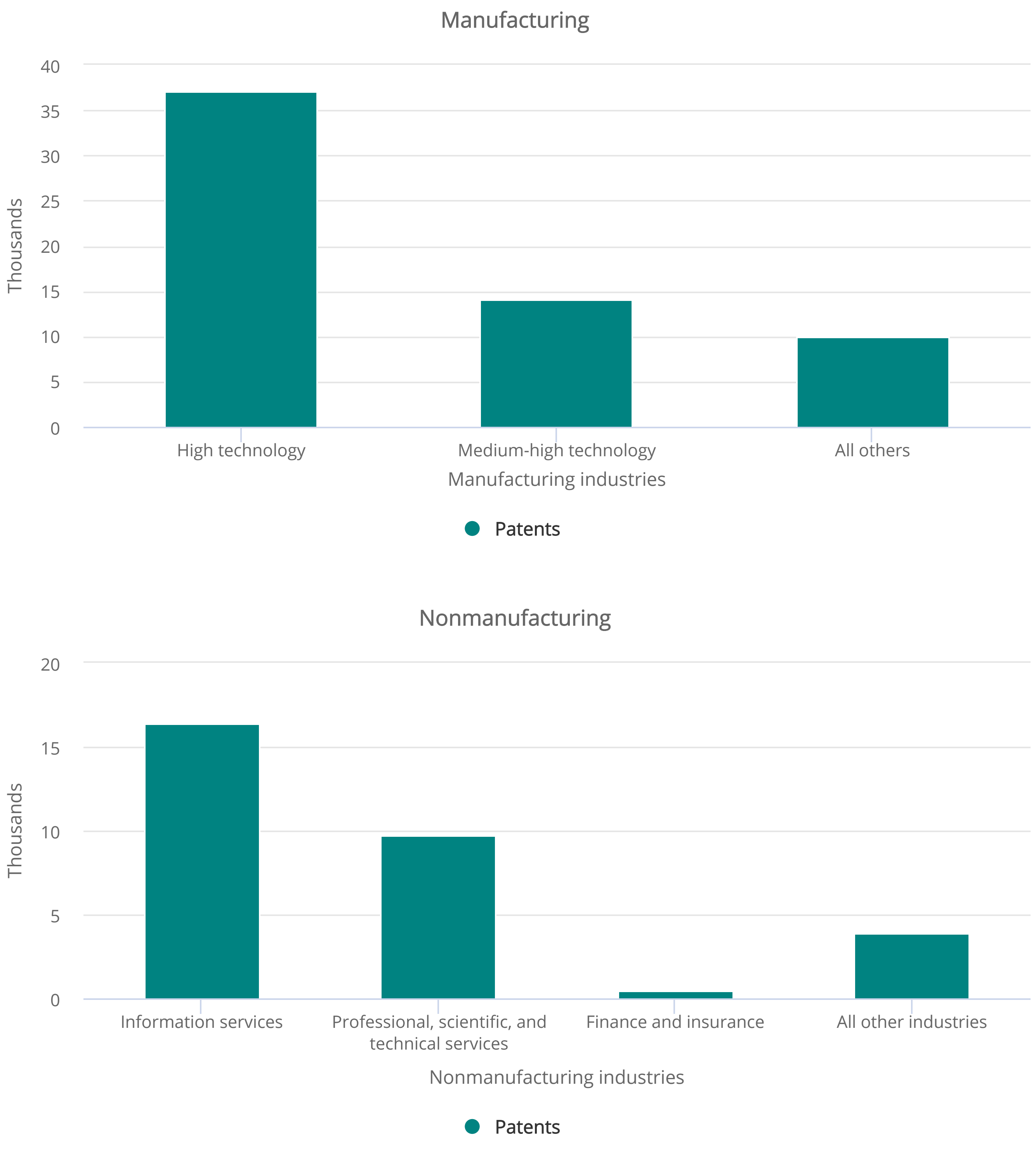
Patenting by U.S. Industries

USPTO data provide information about the technology area for the patent but not the industry in which the inventor or assignee works. Industry-level measures of patenting are available for a more limited set of firms, those in scope for the National Science Foundation (NSF) National Center for Science and Engineering Statistics Business R&D and Innovation Survey (BRDIS), which focuses on the activity of R&D-performing firms. BRDIS data estimate that more than 91,000 patents were issued to R&D performing firms in the United States in 2015. The U.S. knowledge- and technology-intensive industries described in Chapter 6—high-technology manufacturing, medium-high technology manufacturing, and commercial knowledge-intensive services industries—have a far larger share of patents than other industries (Figure 8-2). U.S. high-technology manufacturing industries received 61% of the 61,000 USPTO patents granted to U.S. manufacturing industries in 2015. Medium-high technology manufacturing industries received almost a quarter of these patents. Together, these industries accounted for more than 80% of all patents granted to U.S. manufacturing industries in 2015.

U.S. commercial knowledge-intensive services received 87% of the 30,000 patents granted to nonmanufacturing industries in 2015 (Figure 8-2). The information services industry accounted for 16,000 patents, 62% of the patents granted to commercial knowledge-intensive services; the professional, scientific, and technical services accounted for almost 10,000 patents (37%).

FIGURE 8-2

USPTO patents granted, by selected U.S. industry: 2015



USPTO = U.S. Patent and Trademark Office.

Note(s)

High-technology manufacturing industries include aerospace, communications, computers and office machinery, pharmaceuticals, semiconductors, and testing, measuring, and control instruments. Medium-high-technology manufacturing industries include chemicals excluding pharmaceuticals, motor vehicles and parts, electrical equipment and appliances, machinery and equipment, and railroad and other transportation equipment. Detail may not add to total because of rounding. Industry classification is based on the dominant business code for domestic R&D performance, where available. For companies that did not report business codes, the classification used for sampling was assigned. Statistics are based on companies in the United States that reported to the survey, regardless of whether they did or did not perform or fund R&D. These statistics do not include an adjustment to the weight to account for unit nonresponse. For a small number of companies that were issued more than 100 patents by USPTO, survey data were supplemented with counts from https://www.uspto.gov/, accessed 20 January 2017.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Business R&D and Innovation Survey (BRDIS), 2015.

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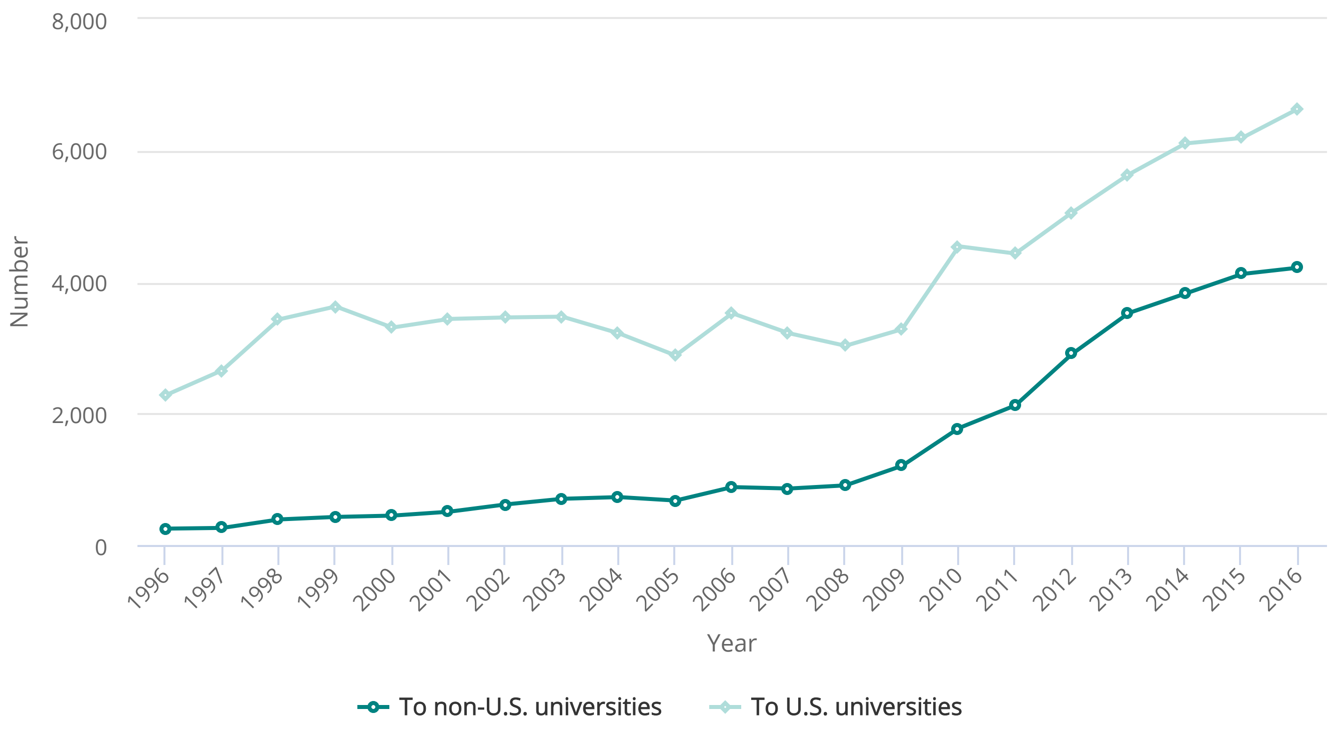
Trends and Patterns in Academic Patenting

Compared with the production of S&E publications (as described in Chapter 5 section Outputs of S&E Research: Publications) patenting is a less-frequent event. For example, in 2016, 409,000 S&E publications were produced by U.S.-affiliated authors, almost 308,000 of these from U.S. academic authors (Appendix Table 5-41). By contrast, in the same year, 151,000 USPTO patents were assigned to U.S. owners (Appendix Table 8-1), and 6,600 of these patents were assigned to U.S. academic owners (Appendix Table 8-2).

These U.S. patents, together with 4,200 patents granted to foreign universities and colleges in 2016, account for just under 11,000 academic patents. Foreign universities have expanded patenting rapidly since 2008, when 900 were granted (Figure 8-3).

FIGURE 8-3

USPTO patents granted to U.S. and non-U.S. academic institutions: 1996–2016



USPTO = U.S. Patent and Trademark Office.

Note(s)

Patents are allocated according to patent ownership information. Patents are credited on a fractional-count basis (i.e., for articles with collaborating institutions, each institutions receives fractional credit on the basis of the proportion of its participating institutions). The sum of patents granted to non-U.S. and U.S. academic institutions is lower than the total number of patents granted to academic institutions as country affiliation of a few academic patents is unknown (data not presented).

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; PatentsView; U.S. Patent and Trademark data, accessed April 2017.

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In a detailed examination of the USPTO data for 2009 to 2014, Leydesdorff, Etzkowitz, and Kushnir (2016) attribute the rapid growth in foreign university patenting to universities in Taiwan, South Korea, Japan, and China. They also found that universities in Saudi Arabia, Norway, and India experienced particularly rapid growth from a small base. The authors found that, unlike the long-term biomedical focus of European and U.S. university patenting, electronics patents are the focus of much of the recent growth in foreign university patents.

Patent data filings include detailed information on technology area, allowing for analysis of trends in patenting over time. The patent indicators described below are classified by technology areas from the World Intellectual Property Organization

(WIPO), summarized into 35 technical fields shown in Appendix Table 8-2 for U.S. university patents for 1996–2016. In 2016, slightly more than half (54%) of all the patents granted to universities were in just 5 of the 35 technical fields: pharmaceuticals, biotechnology, medical technology, organic fine chemistry, and measurement (▦ Table 8-1). For technical areas with more than 100 academic patents, the annual growth rate for 2016 was highest for digital communications (11.1%), microstructural and nanotechnology (9.3%), and computer technology (8.3%).

TABLE 8-1

U.S. university patent awards, by technology area: 2002 and 2016

(Number and percent)

Rank	Technology area	2002	2016	Average annual change (%)	2016 share (%)
-	All university patents	3,461	6,639	4.8	100
1	Pharmaceuticals	575	1,008	4.1	15.2
2	Biotechnology	710	953	2.1	14.4
3	Medical technology	236	683	7.9	10.3
4	Organic fine chemistry	295	480	3.5	7.2
5	Measurement	216	438	5.2	6.6
6	Computer technology	119	406	9.2	6.1
7	Analysis of biological materials	143	296	5.3	4.5
8	Electrical machinery, apparatus, energy	87	264	8.3	4.0
9	Semiconductors	106	244	6.1	3.7
10	Chemical engineering	70	178	6.9	2.7
11	Optics	140	175	1.6	2.6
12	Microstructural and nanotechnology	65	143	5.7	2.1
13	Basic materials chemistry	51	139	7.4	2.1
14	Macromolecular chemistry, polymers	77	131	3.8	2.0
15	Digital communication	25	113	11.3	1.7
16	Materials, metallurgy	62	111	4.3	1.7
17	Other special machines	78	94	1.3	1.4
18	Surface technology, coating	56	87	3.2	1.3
19	Telecommunications	50	85	3.9	1.3
20	Audio-visual technology	37	79	5.6	1.2
21	Engines, pumps, turbines	25	63	6.8	0.9
22	Basic communication processes	20	62	8.4	0.9
23	Environmental technology	43	56	1.9	0.8
24	Control	22	54	6.6	0.8

Rank	Technology area	2002	2016	Average annual change (%)	2016 share (%)
25	Food chemistry	28	41	2.7	0.6
26	Civil engineering	18	36	4.9	0.5
27	Textile and paper machines	20	32	3.6	0.5
28	Transport	16	29	4.4	0.4
29	Mechanical elements	19	27	2.6	0.4
30	Other consumer goods	9	25	7.9	0.4
31	Handling	7	21	7.9	0.3
32	Thermal processes and apparatus	10	19	4.5	0.3
33	IT methods for management	3	19	15.0	0.3
34	Machine tools	17	17	0.2	0.3
35	Furniture, games	4	17	10.7	0.2
36	Unclassified	1	13	19.8	0.2

IT = information technology.

Note(s)

Patents are allocated according to patent inventorship information. Data include institutions affiliated with academic institutions, such as university and alumni organizations, foundations, university associations, and affiliated hospitals. Universities vary in how patents are assigned (e.g., to boards of regents, individual campuses, or entities with or without affiliation with university). Patents are classified under the World Intellectual Property Organization classification of patents, which classifies International Patent Classification codes under 35 technical fields. Fractional counts of patents were assigned to each technological field on patents to assign the proper weight of a patent to the corresponding technological fields under the classification. For instance, a patent that is classified under five different technological fields will see each of its technological fields receive a 0.2 count of the patent so that the patent accounts for a count of 1.0 across all technological fields. Data across technical fields sum up to the total number of granted academic patents in the United States and also sum up to the total number of U.S. Patent and Trademark Office (USPTO) patents granted to academic institutions. See Appendix Table 8-2 for more years of data.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; USPTO patent data, accessed April 2017.

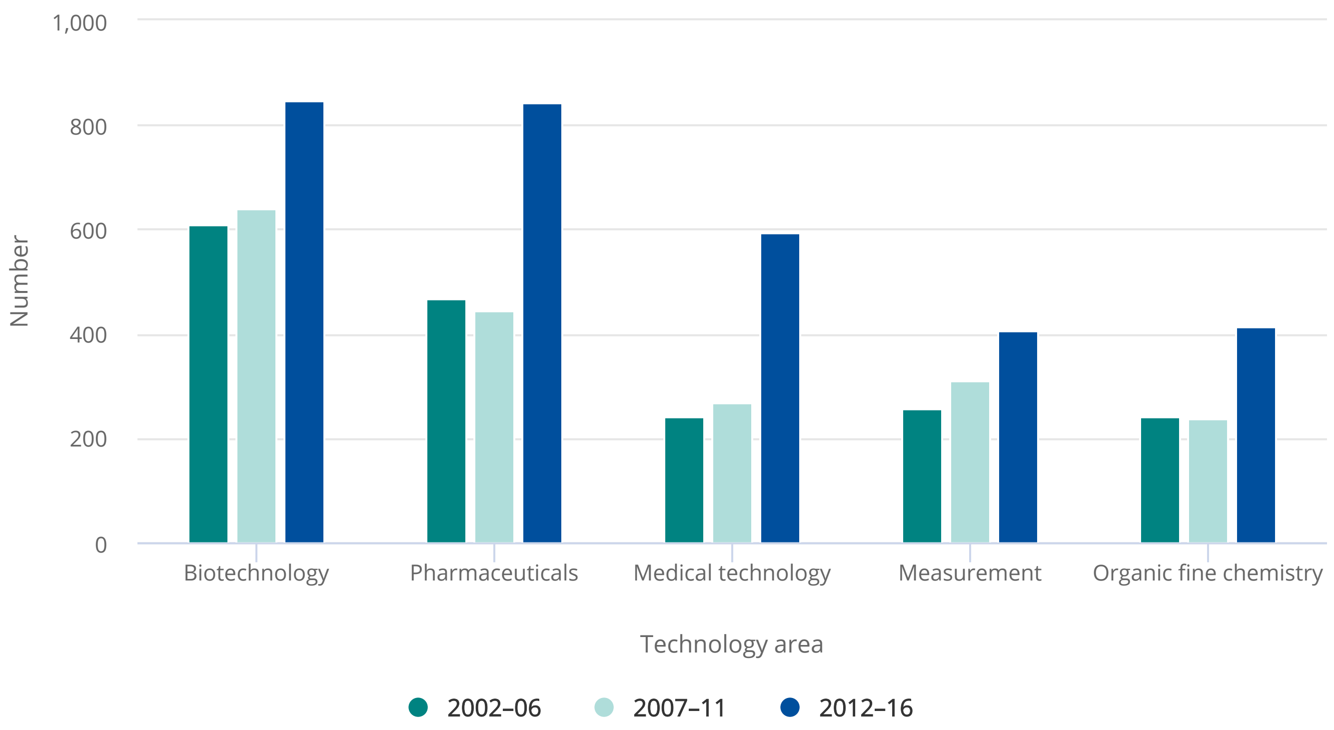
Science and Engineering Indicators 2018

In 2016, just 5 of the 35 technical fields, pharmaceuticals, biotechnology, medical technology, organic fine chemistry, and measurement, accounted for slightly more than half (54%) of all the patents granted to universities (▦Table 8-1). Academic patenting data from USPTO are presented in 35 World Intellectual Property Organization (WIPO) technical fields shown in Appendix Table 8-2. The table shows patent awards for U.S. university patents for 1996–2016.

Although the pharmaceuticals field had the highest number of university patents in the most recent year for which we have data, 1,008 patents in 2016, this reflects a relatively recent trend. Over a longer period since the turn of the century, biotechnology patents had accounted for the largest number of U.S. university patents: Figure 8-4 shows the top five areas for university patenting in 5-year averages between 2002 and 2016. Of these five technical fields, medical technology and measurement, consisting of measurement instruments, have shown continual growth over all three 5-year periods.

FIGURE 8-4

U.S. academic patents, by selected technology area, 5-year averages: 2002–16



Note(s)

Patents are allocated according to patent ownership information.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; PatentsView; U.S. Patent and Trademark Office patent data, accessed April 2017. See Appendix Table 8-2, which includes data for 35 technology areas.

Science and Engineering Indicators 2018

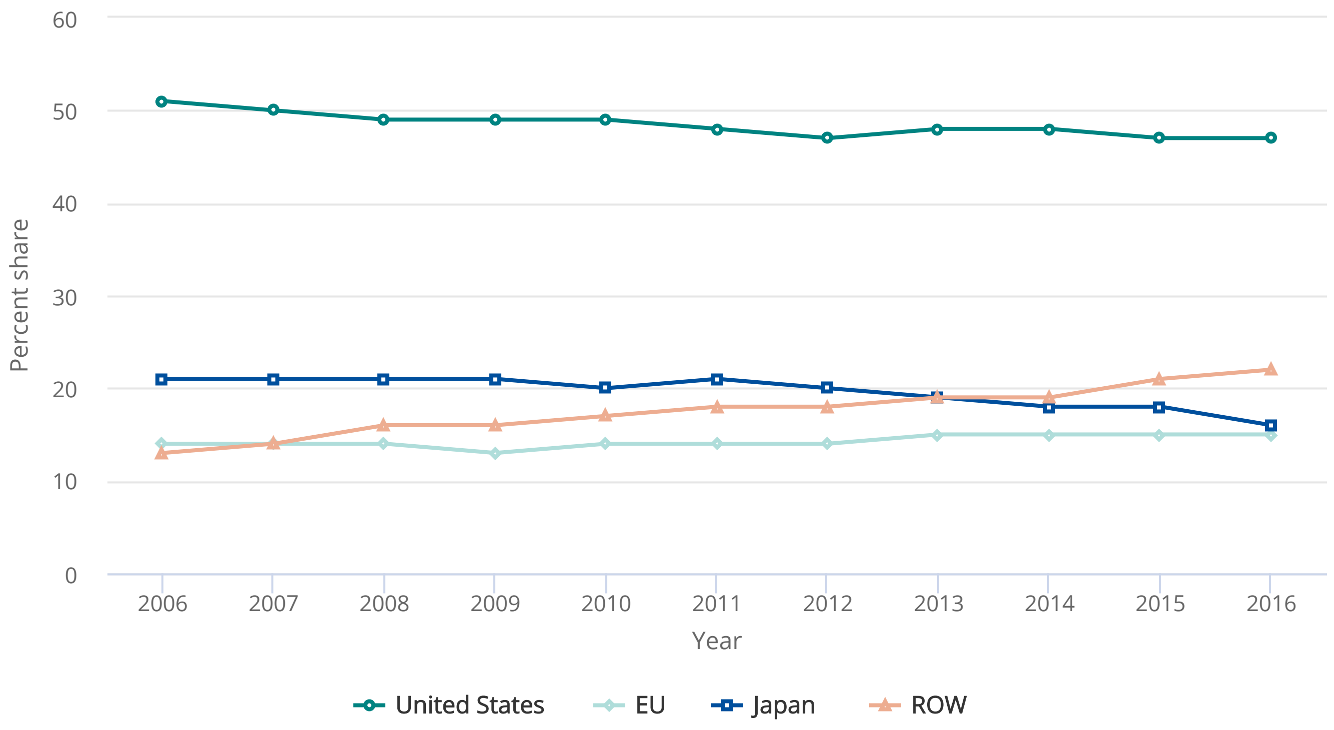
Global Patent Trends and Cross-National Comparisons

Global and Cross-National Activity in USPTO Patents

The data described in this section are based on the geographic address of the inventor. The USPTO granted more than 300,000 patents in 2016 to inventors all over the world (Figure 8-5; Appendix Table 8-3 and Appendix Table 8-4). The United States received nearly half (47%) of them, followed by Japan (16%) and the member countries of the European Union (EU) (15%). Although several developed and developing economies, including South Korea, China, Taiwan, and India, have seen steep increases over time in their USPTO patenting activity, the United States, the EU, and Japan together still account for the clear majority of USPTO patents (Figure 8-5).

FIGURE 8-5

USPTO patents granted, by selected region, country, or economy of inventor: 2006–16



EU = European Union; ROW = rest of world; USPTO = U.S. Patent and Trademark Office.

Note(s)

Patent grants are fractionally allocated among regions, countries, or economies based on the proportion of the residences of all named inventors.

Source(s)

Science-Metrix; SRI International. See Appendix Table 6-37.

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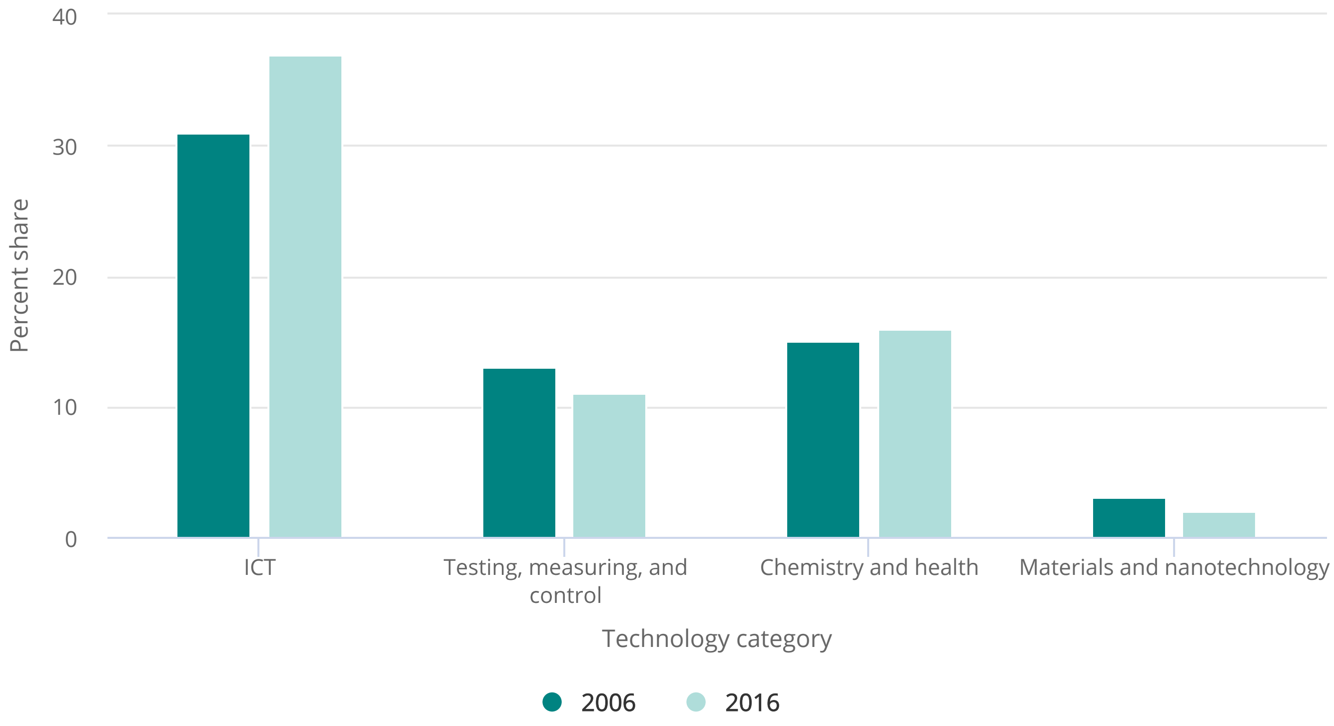
After flat growth for most of the 2000s, the number of USPTO patents grew more than 80% between 2009 and 2016, led by growth of patents in information and communications technologies (ICT) (Figure 8-6; Appendix Table 8-4 through Appendix Table 8-10).

Faster growth of patents granted to non-U.S. inventors reduced the U.S. share from 51% in 2006 to 47% in 2016 (Figure 8-5; Appendix Table 8-4). The increase in foreign patents reflects globalization, as foreign firms file their existing patents in multiple jurisdictions (Fink, Khan, Zhou 2015). Large multinational companies, including those based outside of the United States, are increasingly seeking patent protection beyond their domestic borders.

The pattern of this globalization of USPTO patents has been uneven. Japan's share fell, and the EU's share remained steady between 2006 and 2016 (Figure 8-5; Appendix Table 8-4). Patenting activity in the Asian economies of South Korea, China, and India increased strongly over the last decade (Figure 8-7; Appendix Table 8-4). South Korea's share doubled to reach 6%. China's patenting activity grew the fastest, although from a low base, resulting in its share rising from 1% to 4%. India also grew from a low base, with its share reaching 1%. Although the number of patents more than doubled between 2006 and 2016, Taiwan's global share remained at 4% during this period.

FIGURE 8-6

USPTO patents granted in selected broad technology categories: 2006 and 2016



ICT = information and communications technology; USPTO = U.S. Patent and Trademark Office.

Note(s)

Patents are classified under the World Intellectual Property Organization (WIPO) classification of patents, which classifies International Patent Classification (IPC) codes under 35 technical fields. IPC reformed codes take into account changes that were made to the WIPO classification in 2006 under the eighth version of the classification and were used to prepare these data. However, because PatentsView only provides the original IPC codes as they appeared on patents and not the IPC reformed codes, current Cooperative Patent Classification codes on patents were converted back to the most recent IPC classification to prepare these statistics. Fractional counts of patents were assigned to each technological field on patents to assign a proper weight of a patent to the corresponding technological fields under the classification. Patents are fractionally allocated among regions, countries, or economies based on the proportion of residences of all named inventors.

Source(s)

Science-Metrix; PatentsView; SRI International, accessed December 2016. See Appendix Table 6-37 through Appendix Table 6-48.

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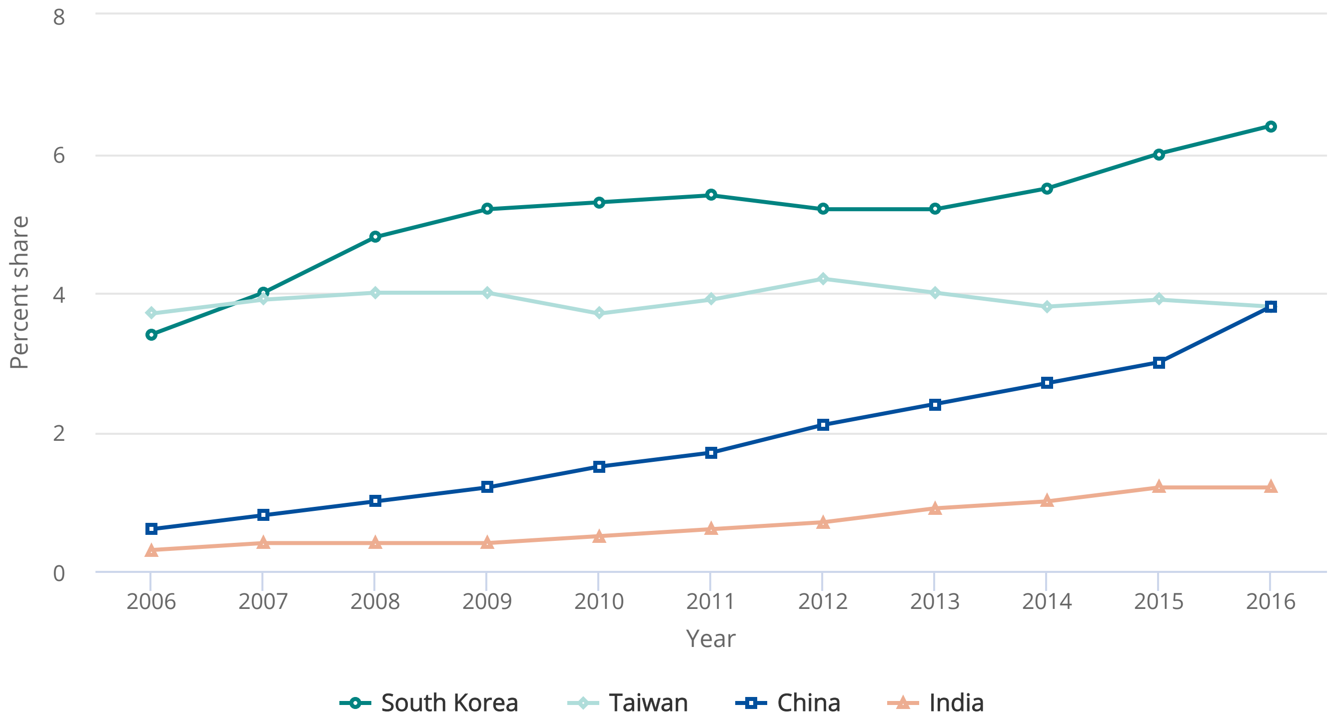
FIGURE 8-7

USPTO patents granted, by selected country or economy of inventor: 2006–16



USPTO = U.S. Patent and Trademark Office.

Note(s)

China includes Hong Kong. Patent grants are fractionally allocated among regions, countries, or economies based on the proportion of the residences of all named inventors.

Source(s)

Science-Metrix; LexisNexis; SRI International. See Appendix Table 6-37.

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Patenting in selected technologies

This section discusses patterns and trends of four technology categories that are closely linked to science or the knowledge- and technology-intensive industries described in Chapter 6: ICT; testing, measuring, and control; chemistry and health; and materials and nanotechnology (Table 8-2). The patent count data by country for some of the 35 WIPO patent fields shown in Appendix Table 8-2 are reorganized into these four broader categories. The ICT category, consisting of six technologies, has the largest share of USPTO patents (37% of all USPTO patents in 2016) (Figure 8-6). Patents granted in these fields are shown in Appendix Table 8-5 through Appendix Table 8-10. Of ICT, computer technology is the largest in terms of USPTO patent share (14%), followed by digital communication (10%), semiconductors (6%), and telecommunications (4%). The next largest category is chemistry and health (16%), consisting of seven technologies; medical technology has the largest share (6%) among these technologies. Patents granted in these fields are shown in Appendix Table 8-11 through Appendix

Table 8-17. The third largest (11%) is testing, measuring, and control, consisting of four technologies (Appendix Table 8-18 through Appendix Table 8-21). Materials and nanotechnology, consisting of three technologies, has a far smaller share (2%) (Appendix Table 8-22 through Appendix Table 8-24).

TABLE 8-2

Selected technology areas of USPTO patents

(Technology areas)

Broad category	Technology area
Information and communications technologies	Communication process
	Computer
	Digital communications
	Information technology methods for management
	Semiconductors
	Telecommunications
Testing, measuring, and control	Analysis of biological materials
	Control
	Measurement
	Optics
Chemistry and health	Pharmaceuticals
	Biotechnology
	Basic material chemistry
	Organic chemistry
	Macromolecular chemistry
	Chemical engineering
	Medical technology
Materials and nanotechnology	Materials and metallurgy
	Microstructural and nanotechnology
	Surface technology and coating

USPTO = U.S. Patent and Trademark Office.

Note(s)

Patents are classified under the World Intellectual Property (WIPO) classification of patents, which classifies International Patent Classification (IPC) codes under 35 technical fields. IPC reformed codes take into account changes that were made to the WIPO classification in 2006 under the eighth version of the classification.

Source(s)

Science-Metrix; PatentsView; SRI International.

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The number of ICT patents nearly doubled between 2006 and 2016, the fastest growth of these four technology categories. The ICT share of all patents increased from 31% to 37% during this period (Figure 8-6). For example, the average smartphone, which uses a wide variety of ICT, is covered by around 250,000 patents, up from 70,000 patents in 2003 (Reidenberg 2015). In addition, patents of technical standards, guidelines, or specifications that govern the interaction of technologies in products, processes, and services, grew rapidly. Technical standards are used widely in ICT technologies, including smartphones (see sidebar Technical Standards, Invention, Innovation, and Economic Growth). The growth in ICT patents over the last decade was led by digital communication (195%) and computer technology (126%).

Patents in the chemistry and health category grew slightly faster (84%) than all patents (75%) between 2006 and 2016 (Figure 8-6; Appendix Table 8-11 through Appendix Table 8-17). Medical technology patents grew the fastest among this category (140%), resulting in its share of all patents rising from 4% to 6%. Two other technologies—pharmaceuticals (Appendix Table 8-13) and basic material chemistry (Appendix Table 8-14)—also had strong growth.

Patents in the testing, measuring, and control category grew significantly slower than all patents (43%) over the last decade (Figure 8-6; Appendix Table 8-18 through Appendix Table 8-21). Within this category, patents in analysis of biological materials grew the fastest (84%), albeit from a very low base. Patents in control technology grew modestly (74%).

Patents in the materials and nanotechnology category grew slower than all patents over the last decade (Figure 8-6; Appendix Table 8-22 through Appendix Table 8-24). Patents in materials and metallurgy and in surface technology and coating had modest growth; patents in microstructural and nanotechnology grew slightly (10%).

SIDEBAR

Technical Standards, Invention, Innovation, and Economic Growth

A technical standard is "a document that provides requirements, specifications, guidelines or characteristics that can be used consistently to ensure that materials, products, processes and services are fit for their purpose."* Standards are widely used in industries and firms that produce, use, or rely on information and communications technologies. A technical standard may be developed privately or unilaterally (e.g., by a corporation or regulatory body, by groups such as trade unions and trade associations). Standards organizations often have more diverse input and usually develop voluntary standards. For example, the International Organization for Standardization (ISO) develops innovation management standards.†

One example of a technical standard is Apple's operating system for the iPhone, which governs the interface and function of the large number of iPhone applications (apps). Apple's technical standards allow many companies and developers to provide apps that increase the iPhone's utility, value, and desirability. A second example is the National Institute of Standards and Technology (NIST) ThermoData Engine Standard Reference Database. This database enables U.S. chemical companies to save valuable time and expense by using simulations rather than running full-scale experiments to design their products and assess the safety and efficiency of their manufacturing processes.

The number of standards is proliferating in the global economy, coinciding with the globalization of high-technology value chains and the complexity and pervasiveness of technologies embedded in products and services. The growth of shared platforms such as the Internet and cellular telephony has been a significant driver in the growing demand for standards. For example, the semiconductor industry is estimated to have at least 1,000 standards.

Researchers and policymakers are increasingly interested in standards because they appear to play an important role in facilitating technological development, innovation, and increasing economic growth. Several studies have found that standards are significantly associated with economic growth through greater diffusion of knowledge. However, the impact of standards on innovation and economic growth is not fully understood because of these standards' complexity and the limited amount of research in this area. Furthermore, the existing research has mostly focused on developed countries, with few studies on China and other developing countries (Ernst 2013:5). The limited amount of research suggests that standards increase industry growth and productivity, which can increase a country's economic growth. One study found the following wide-ranging impacts of standards on economic growth and innovation (Tassey 2015:189–90):

- Raising the efficiency of R&D
- Expanding existing markets and creating new markets for an industry's products and services
- Increasing the growth and productivity of incumbent firms
- Facilitating the entry of small and medium-sized firms, which can increase innovation and growth of the entire industry

The rapid growth of standards has coincided with a boom in standard essential patents (SEPs), which cover technologies that are part of standards. A company needs these patents to produce any product that meets the specifications defined in the standard when it is not possible to comply with the standard without infringing on the intellectual property protected by the SEP. A company can make a standard-compliant product by owning the SEPs or by licensing SEPs owned by others.

SEPs are considered crucial for achieving rapid, broad-based diffusion of knowledge to stimulate innovation. However, research suggests that SEPs can hinder the positive economic and social benefits of standards because of several factors, including uncertainty about whether an SEP is really essential, lack of transparency of the licensing conditions, market-distorting patenting strategies, and costly and time-consuming litigation (Ernst 2016:2–3). The growing number of SEPs increases the likelihood of “royalty stacking,” where the cumulative payable royalties for SEPs exceeds a reasonable level or may even become prohibitive for implementing products (Ernst 2016:5). In addition, many technologies that are patented in standards are not considered essential.

Standards consist of two types: product and non-product. Product standards govern the performance and function of components used in high-technology products and prescribe procedures to test product development, production, and market transactions. In the United States, businesses have typically developed product standards by reaching voluntary consensus with relevant stakeholders, including firms in the industry, suppliers, and R&D laboratories.

Nonproduct standards have more general and broader functions than product standards. These standards generally govern the efficiency, operation, and performance of the entire industry. Examples include measurement and test methods, interface standards, scientific and engineering databases, and standard reference materials (Tassey 2015:192). Nonproduct standards have become increasingly important because many high-technology products are a complex mix of goods and services.

The two types of nonproduct standards are technical and basic. Technical nonproduct standards are operational, applied functions and guidelines that govern the performance, function, and interaction of services and products. U.S. industries have also developed technical nonproduct standards through a voluntary consensus approach. The second type is basic nonproduct standards, which include generic measurement and test methods that are typically derived from fundamental scientific principles, such as the laws of physics. Although these standards have wide applications in industry, firms and even industries tend to underinvest because they are expensive and require an extensive and specialized scientific infrastructure. Therefore, basic standards are considered a public good and usually have some degree of public involvement in many developed countries. NIST provides this function for the United States.

* ISO is the source of this definition (https://www.iso.org/standards.html).

† For more information on ISO’s work on innovation management standards, see https://www.iso.org/committee/4587737.html.

Country-level concentration in patenting technology areas

In contrast to growth rates, patent activity indexes provide insight into the areas where each country is concentrating its patenting activity. As noted previously, many factors, including industry-level propensity to patent and patent litigation, influence patenting activity. This section presents patent activity indexes of the United States, the EU, and several Asian economies in these technologies averaged for 2014–16, based on analysis of USPTO data. The Patenting Activity Index indicates the extent to which a country’s patents are concentrated in a particular technology. It is an output measure of specialization, assessing the share of a country’s patents produced in each technological area. The indicator is computed by comparing a country to the global average (see sidebar Patent Data Analytics and Terminology). Technologies with an activity index of 1.2 or more are defined here as relatively more concentrated.

SIDEBAR

Patent Data Analytics and Terminology

USPTO Data

The patents referred to in analyses throughout *Science and Engineering Indicators 2018* are registered with the U.S. Patent and Trademark Office (USPTO), the federal agency responsible for handling patent and trademark applications in the United States. USPTO executes these processes for U.S. intellectual property management, coordinating more than 6,000 patent examiners and 5 patent offices across the United States, and it provides access to its data through several different portals.

PatentsView Database

PatentsView is the data source used for much of the analyses of patenting behavior presented in *Science and Engineering Indicators 2018.* It is a data analysis and visualization platform for USPTO data developed by USPTO in collaboration with other federal agencies and academic institutions. In addition to parsing, structuring, and standardizing patent data, the PatentsView initiative makes considerable efforts to disambiguate names and locations in USPTO patent data while also associating patents with their relevant technology fields based on multiple taxonomies.

Patent Technology Areas

The PatentsView database classifies patents under four different taxonomies: Cooperative Patent Classification, World Intellectual Property Organization (WIPO), U.S. Patent Classification, and National Bureau of Economic Research. For *Science and Engineering Indicators 2018*, the WIPO classification is applied, which divides patents into 35 categories based on International Patent Classification (IPC) codes. Each patent can be tagged with multiple IPC codes and can thus fall under multiple WIPO technology areas. The U.S. Patent Classification is also used to identify patents related to clean technologies.

Matching Citations to Nonpatent Literature

Patents cite other patents, showing how a novel invention builds on and distinguishes itself from other patents within the existing technological ecosystem. Some citations show the connection between inventions and a broader ecosystem, citing nonpatent literature (NPL). Matching these citations to peer-reviewed scientific publications is of interest as a means by which to assess the uptake of research in subsequent development efforts.

The matching of NPL citations from PatentsView to records in Scopus is done by an algorithm that extracts and parses publication titles; publication years; author names; and names or abbreviated names of research journals and conference proceedings, volume and issue numbers, and page ranges. These extracted data are then algorithmically compared with information extracted from the Scopus database (see sidebar Bibliometric Data and Terminology in Chapter 5) to match NPL citations in PatentsView to their cited publications appearing in Scopus.

***Patent-Related Indicators in* Indicators 2018**

Patents Granted

This indicator reflects the number of patents granted to a country, sector, or organization. Patents are attributed using the fractional counting method (see sidebar Bibliometric Data and Terminology in Chapter 5). Patents also have inventors (one or more) and grantees, where the latter become the owners of the intellectual property covered by the patent. For most scores presented in this chapter, this indicator presents the fractional count of patents by inventor, although some present information by grantee; the notes for tables and figures always specify the approach. More than 143,000 patents were granted to U.S. inventors in 2016 (Appendix Table 8-4).

Patenting Activity Index

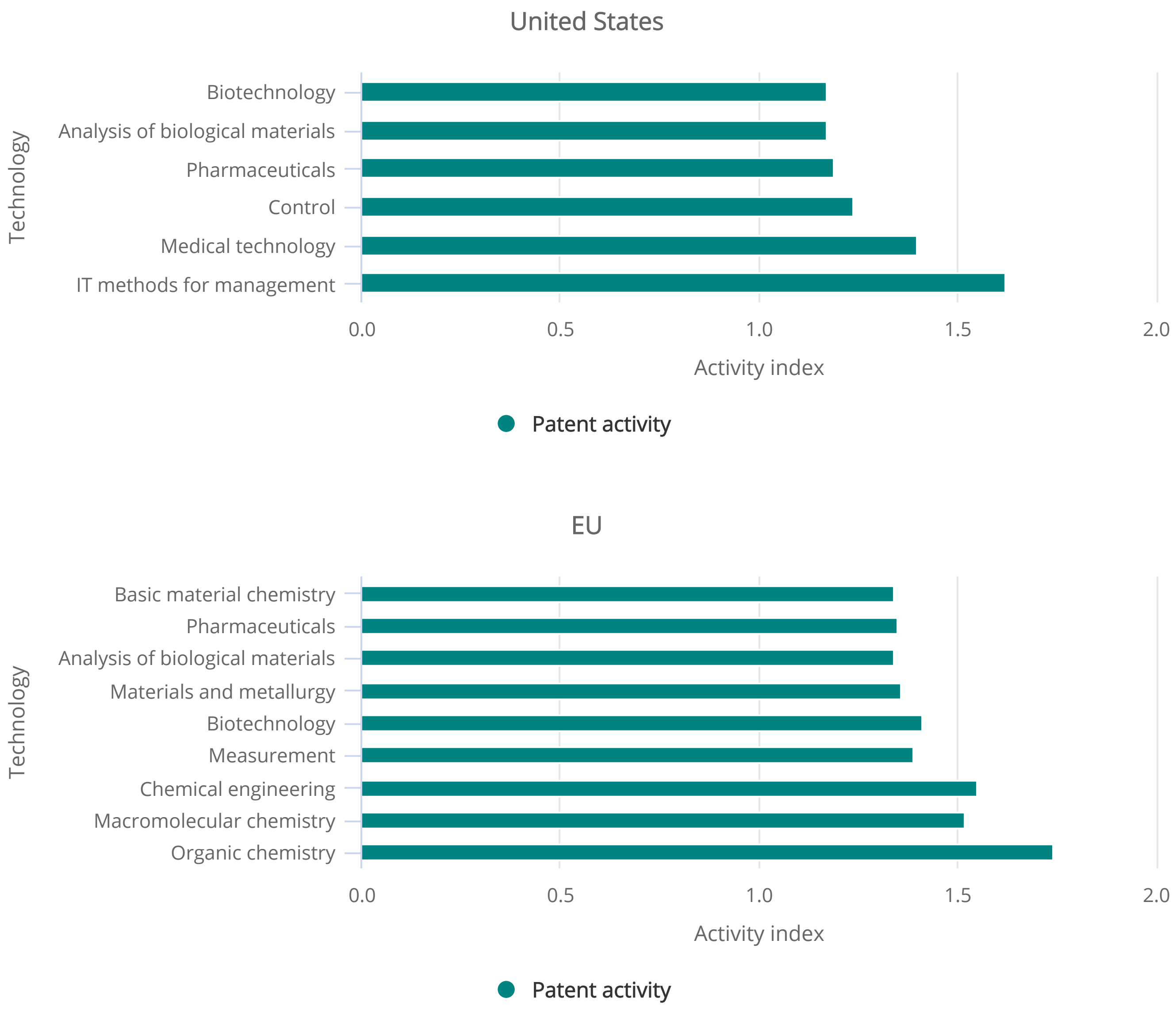
For any given area of technological development, the Patenting Activity Index indicates the extent to which a country specializes in that area. It is an output measure of specialization, assessing the share of a country's patents produced in each technological area. The indicator is computed by comparing a country to the global average. In 2016, for instance, the United States produced about 3,300 of its 143,000 patents in IT methods for management. By comparison, at the world level, only about 4,400 of 304,000 total patents were granted in IT methods for management (Appendix Table 8-4 and Appendix Table 8-10. Thus, the United States produces more patents in this area than expected, based on its total output and the world proportions.

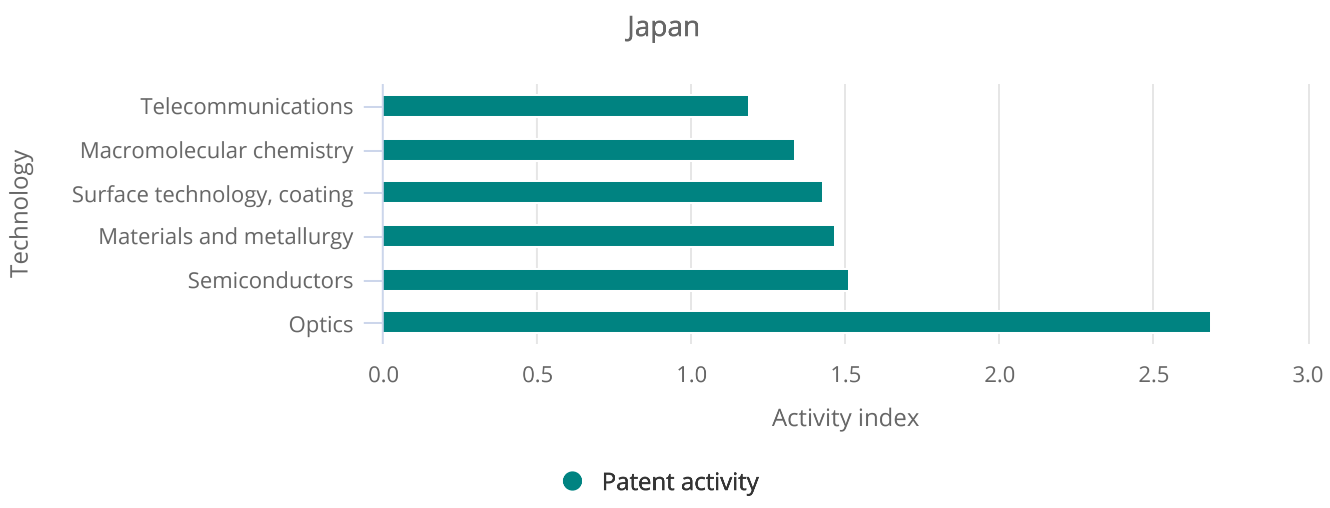
This indicator is indexed to 1.00, which represents the world level, meaning that a score above 1.00 shows that a country produces more of its patent output in the given technological area than the global proportion, whereas a score below 1.00 shows that a country produces fewer patents in this technological area than the global average. Whenever a country's share of patents in one area increases, its share in other areas must decrease proportionately.

Patenting in the United States is relatively more concentrated in six technologies (Figure 8-8; Appendix Table 8-25). Three of these are in the chemistry and health category—medical technology, pharmaceuticals, and biotechnology. The United States has a high concentration in analysis of biological materials, a technology classified in the testing, measuring, and control category, that is closely related to the chemistry and health category. The concentration of U.S. patenting activities in pharmaceuticals, analysis of biological materials, and biotechnology coincides with the strong U.S. market position in and considerable R&D investment in pharmaceuticals. The U.S. concentration in medical technology and control technologies coincides with a strong market position in testing, measuring, and control instruments. U.S. patenting is concentrated in one technology in the ICT category, information technology (IT) methods for management, which consists of business methods and software methods for data processing.

FIGURE 8-8

Patent activity index for selected technologies for the United States, the EU, and Japan: 2014–16





EU = European Union; IT = information technology.

Note(s)

A patent activity index is the ratio of a country's share of a technology area to its share of all patents. A patent activity index greater (less) than 1.0 indicates that the country is relatively more (less) active in the technology area. Patents are classified under the World Intellectual Property Organization (WIPO) classification of patents, which classifies International Patent Classification (IPC) codes under 35 technical fields. IPC reformed codes take into account changes that were made to the WIPO classification in 2006 under the eighth version of the classification and were used to prepare these data. However, because PatentsView only provides the original IPC codes as they appeared on patents and not the IPC reformed codes, current Cooperative Patent Classification codes on patents were converted back to the most recent IPC classification to prepare these statistics. Fractional counts of patents were assigned to each technological field on patents to assign the proper weight of a patent to the corresponding technological fields under the classification. Patents are fractionally allocated among regions, countries, or economies based on the proportion of residences of all named inventors.

Source(s)

Science-Metrix; PatentsView; SRI International, accessed April 2017.

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The EU's USPTO patenting is relatively more concentrated in nine technologies, with six that are in the chemistry and health category (Table 8-2; Figure 8-8; Appendix Table 8-25). The EU has a relatively high concentration in organic chemistry (1.7) and relatively high concentrations (1.3–1.6) in six other technologies: macromolecular chemistry, chemical engineering, biotechnology, pharmaceuticals, and basic material chemistry. The relatively high concentration in pharmaceuticals and biotechnology coincides with the EU's strong market position in pharmaceuticals. In the testing, measuring, and control category, the EU is relatively more concentrated in measurement (1.4), which is consistent with the EU's relatively strong market position in testing, measuring, and control instruments. The EU is relatively less concentrated in all technologies in the ICT category.

Japan's concentration of USPTO patenting is far different from that of the United States or the EU. Japan has a very high concentration in optics (2.7), a technology in the testing, measuring, and control category, coinciding with dominance of Japanese-based companies in photography and imaging, including Canon, Fujifilm, Nikon, and Olympus (Table 8-2; Figure 8-8; Appendix Table 8-25). Japan has a moderately high concentration in two technologies in the ICT category—

semiconductors (1.5) and telecommunications (1.2)—despite its considerable loss of market share in these two industries. Japan has a relatively high concentration in two technologies in the materials and nanotechnology category—surface technology and coating (1.4) and materials and metallurgy (1.5).

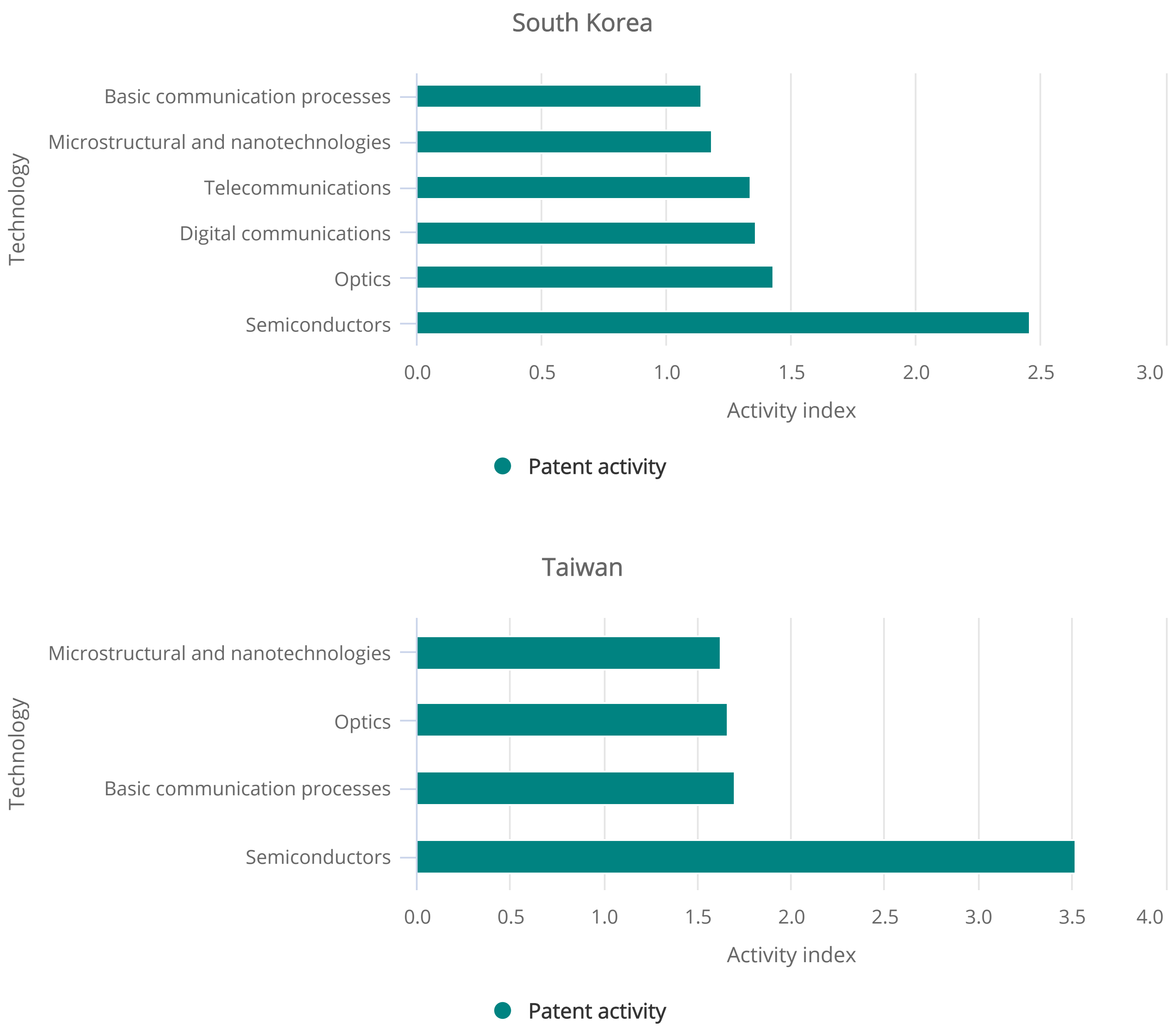
South Korea is relatively more concentrated in four technologies in the ICT category—semiconductors, digital communications, telecommunications, and basic communication processes (Table 8-2; Figure 8-9; Appendix Table 8-25). South Korea's concentration in patenting of these technologies, particularly semiconductors, coincides with its strong market position in the ICT manufacturing industries of semiconductors and communications. South Korea, like Japan, has a relatively high concentration in optics.

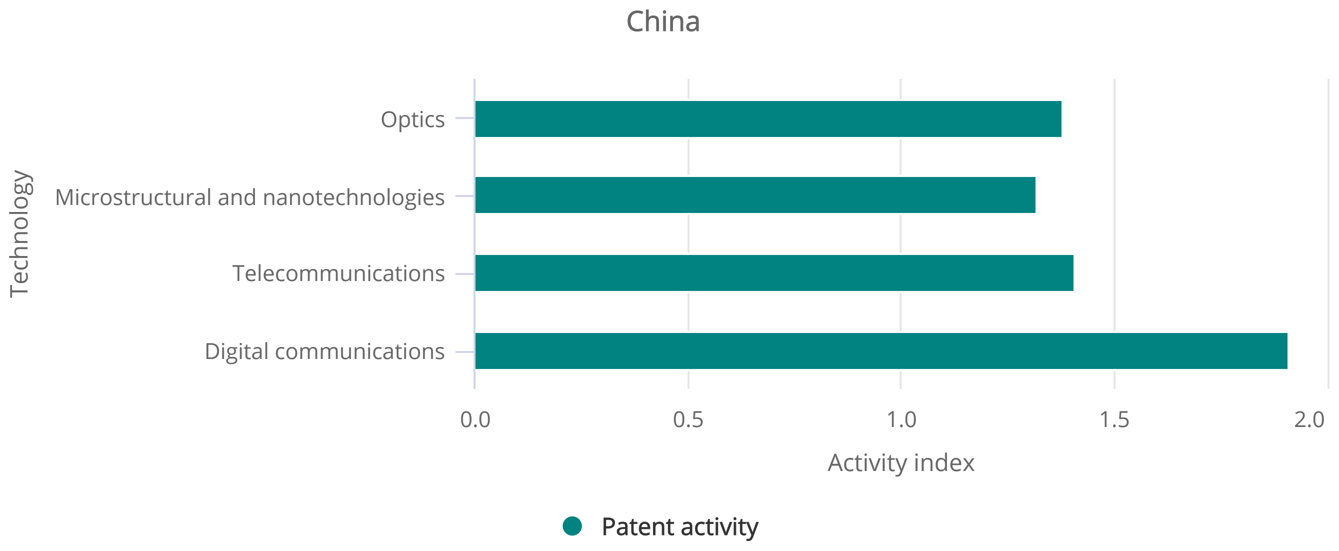
Taiwan has a high concentration in two technologies in the ICT category: semiconductors, coinciding with its very strong market position in the semiconductors industry, and basic communication processes (Figure 8-9; Appendix Table 8-25). Taiwan, like Japan and South Korea, has a relatively high concentration in optics. Taiwan has a relatively high concentration in microstructural and nanotechnologies in contrast to the relatively low concentrations of the United States, the EU, Japan, and South Korea.

China has a relatively high concentration in four technologies, including two technologies in the ICT category—telecommunications and digital communications (Table 8-2; Figure 8-9; Appendix Table 8-25). China has a lower concentration in semiconductors. This is consistent with its technological development, where its industry lags behind firms based in South Korea, Taiwan, and other countries. China, like Taiwan, has a relatively high concentration in microstructural and nanotechnologies.

FIGURE 8-9

Patent activity index of selected technologies for South Korea, Taiwan, and China: 2014–16





Note(s)

A patent activity index is the ratio of a country's share of a technology area to its share of all patents. A patent activity index greater (less) than 1.0 indicates that the country is relatively more (less) active in the technology area. Patents are classified under the World Intellectual Property Organization (WIPO) classification of patents, which classifies International Patent Classification (IPC) codes under 35 technical fields. IPC reformed codes take into account changes that were made to the WIPO classification in 2006 under the eighth version of the classification and were used to prepare these data. However, because PatentsView only provides the original IPC codes as they appeared on patents and not the IPC reformed codes, current Cooperative Patent Classification codes on patents were converted back to the most recent IPC classification to prepare these statistics. Fractional counts of patents were assigned to each technological field on patents to assign the proper weight of a patent to the corresponding technological fields under the classification. Patents are fractionally allocated among regions, countries, or economies based on the proportion of residences of all named inventors.

Source(s)

Science-Metrix; PatentsView; SRI International, accessed December 2016.

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[1] Figure 8-1 shows 2011 data because that is the most recent year for which these data are available for R&D-performing firms as well as firms that do not perform R&D. For R&D-performing firms, these data are available from NSF's 2015 BRDIS.

Knowledge Transfer

Scientific discoveries and inventions flow into economic activity through market-based and freely provided activities. Flows of both types can occur through person-to-person exchange or through access to formal or codified knowledge. *Technology transfer* is “the process by which technology or knowledge developed in one place or for one purpose is applied and used in another place for the same or different purpose” (Federal Laboratory Consortium for Technology Transfer [FLC] 2013:3). Academic, government, business, and nonprofit organizations have policies and programs to help bring knowledge and technology into hands of those with abilities to apply, further develop, and eventually commercialize their research. For example, technology management and transfer offices support patenting or otherwise protected research produced in their institutions’ laboratories to enable potential use through licensing by others or as the basis for a startup firm. Federal agencies and their laboratories, as well as U.S. academic research institutions, have established technology management and transfer offices to support the transmission of their research.

This section begins with a presentation of technology transfer metrics for universities and for federal agencies and their laboratories. These metrics include invention disclosures, patents, and licensing. For academic institutions, data on royalties and startup formation are presented. For federal agencies and their laboratories, cooperative R&D agreement counts are also presented. Next, coauthorship counts of peer-reviewed S&E literature and citations of S&E articles in patents provide indicators of the flow of knowledge from S&E literature to potentially commercializable inventions. The knowledge transfer section ends with the discussion and presentation of international transaction data on licensing and royalties, a market-based measure of trade in knowledge products and intellectual property.

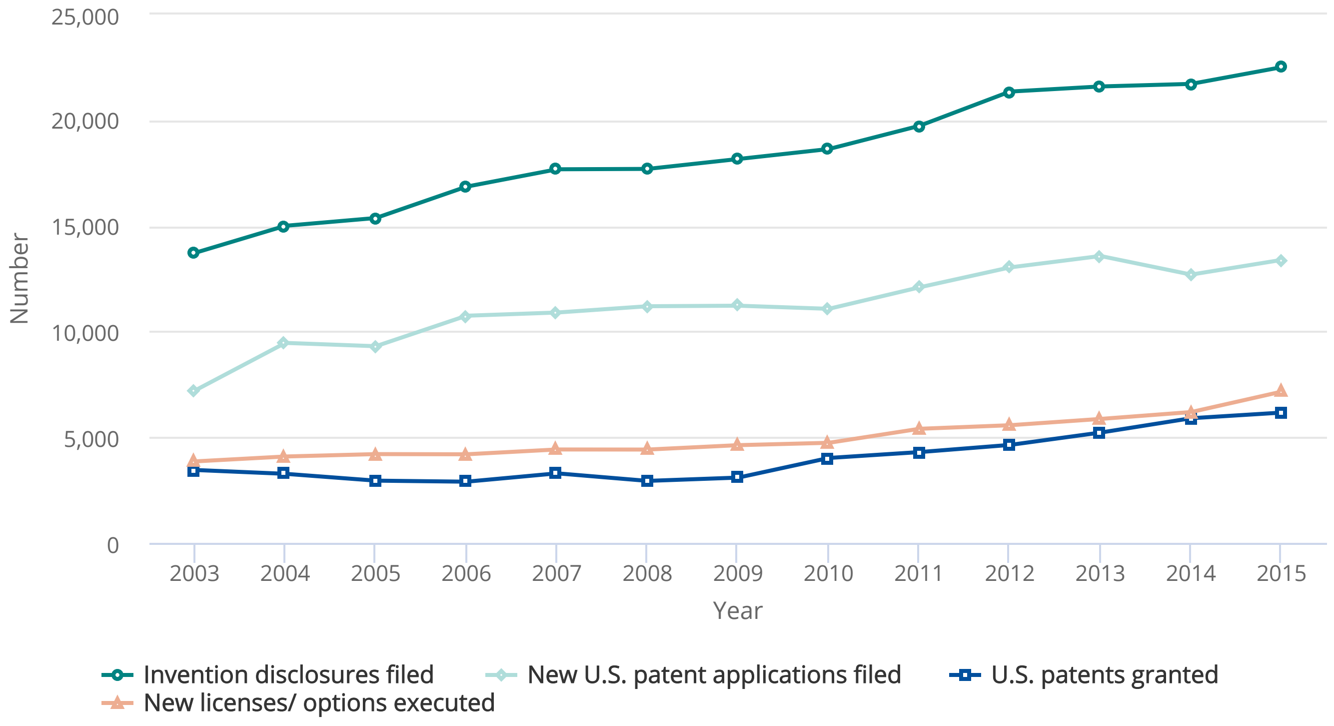
Knowledge Transfer Activities by Academic Institutions

Collaborative R&D activities among universities and colleges, businesses, and other parties have taken place in the United States throughout the 20th and early 21st century. And as federal funding of academic research expanded in the post–World War II era, academic administrations became increasingly engaged in patent management (Mowery et al. 2004). The Bayh–Dole Act (Patent and Trademark Act Amendments of 1980, P.L. 96–517) created a uniform patent policy among the many federal agencies that fund research, enabling small businesses and nonprofit organizations, including universities, to retain ownership of inventions made under federally funded research programs. The Bayh-Dole Act has since been engaged by large companies as well. It is widely regarded as having been an important stimulant since its 1980 enactment for academic institutions to pursue technology transfer activities. Other countries implemented policies like the Bayh–Dole Act by the early 2000s, giving their academic institutions (rather than inventors or the government) ownership of patents resulting from government-funded research (Geuna and Rossi 2011).

The Association of University Technology Managers (AUTM) gathers information on the invention and main patent-related activities of its member universities. Invention disclosures filed with university technology management and transfer offices describe prospective inventions and are submitted before a patent application is filed. The number of these disclosures grew from 13,718 in 2003 to 22,507 in 2015 (notwithstanding small shifts in the number of institutions responding to the AUTM survey over the same period) (📊 Figure 8-10). Likewise, new U.S. patent applications filed by AUTM university respondents also increased, nearly doubling from 7,203 in 2003 to 13,389 in 2015. As described earlier for all U.S. academic patents, U.S. patents awarded to AUTM respondents stayed flat between 2003 and 2009, before rising to reach 6,164 in 2015 (see Appendix Table 8-26).

FIGURE 8-10

U.S. university patenting activities: 2003–15



Source(s)

Association of University Technology Managers (AUTM), AUTM Licensing Surveys: 2003–15. See Appendix Table 8-26.

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Data from AUTM also provide counts of new startups formed and of startups still operating, and these indicators also show an increased growth rate since 2009. New startups reached 950 in 2015 with the number of past startups still operating 4,757 in 2015 (Appendix Table 8-26). Active licenses increased from 18,845 in 2001 to 40,402 in 2015.

While license income is not the dominant objective of university technology management offices (Thursby, Jensen, and Thursby 2001), the 165 institutions that responded to the AUTM survey reported a total of $1.8 billion in net royalties from their patent holdings in 2015. This amount has grown from $754 million in 2001 (Appendix Table 8-26).

Knowledge Transfer Activities by Federal R&D Facilities

The Stevenson-Wydler Technology and Innovation Act of 1980 (P.L. 96–480) directed federal agencies with laboratory operations to become active in the technology transfer process. It also required these agencies to establish technology transfer offices (termed Offices of Research and Technology Applications) to assist in identifying transfer opportunities and establishing appropriate arrangements for transfer relationships with nonfederal parties. Follow-on legislation in the 1980s and through 2000 amending the Stevenson-Wydler Act has worked to extend and refine the authorities available to the agencies and their federal laboratories to identify and manage intellectual assets created by their R&D and to participate in collaborative R&D relationships with nonfederal parties, including private businesses, universities, and nonprofit organizations (FLC 2013).

As indicated in Chapter 4, about 11% of the current U.S. R&D total ($54.3 billion of $495.1 billion in 2015; see ▦ Table 4-1 in Chapter 4) is performed by the federal government, through federal agencies' own research facilities and the 41 federally funded research and development centers (FFRDCs). In response to these longstanding federal policies promoting technology transfer, nearly all the agencies and their associated federal laboratories have become active in recognizing and promoting the transfer of inventions from their own R&D with potential for commercial applications.

As applied in the federal setting, technology transfer can occur through varied channels: *commercial transfer* (the movement of knowledge or technology developed by a federal laboratory to private organizations or the commercial marketplace), *scientific dissemination* (publications, conference papers, and working papers distributed through scientific or technical channels, or other forms of data dissemination), *export of resources* (federal laboratory personnel made available to outside organizations with R&D needs, through collaborative agreements or other service mechanisms), *import of resources* (outside technology or expertise brought in by a federal laboratory to enhance existing internal capabilities), and *dual use* (development of technologies, products, or families of products with commercial and federal [mainly military] applications).

The metrics on federal technology transfer continue to primarily track the number of activities—that is, invention disclosures, patent applications and awards, licenses to outside parties of patents and other intellectual property, and agreements to conduct collaborative research with outside parties (Institute for Defense Analyses, Science and Technology Policy Institute 2011). Nonetheless, systematic documentation of the downstream outcomes and impacts of transfer remains a challenge.[1] Also missing (until most recently) for most agencies and their laboratories are comprehensive data on technology transfer through the *scientific dissemination* mode (i.e., technical articles published in professional journals, conference papers, and other kinds of scientific communications), which remains widely regarded by laboratory scientists, engineers, and managers (federal and private sector) as a key means of transfer. The Department of Commerce's (DOC's) most recent *Summary Report* on federal laboratory technology transfer (with data on FY 2014, published October 2016) is expanded to include a bibliometric analysis of scientific/technical publications originating from federal laboratories (DOC/National Institute of Standards and Technology [NIST] 2016). Additional perspective on this topic is provided earlier in ▦ Table 5-25 in Chapter 5, where an original bibliometric analysis conducted for *Science and Engineering Indicators* contrasts the share of U.S. S&E articles in 2016 for the federal government with that for other performers.

Seven agencies account for most of the annual total of federal technology transfer activities: Department of Defense (DOD), Department of Health and Human Services (HHS), Department of Energy (DOE), National Aeronautics and Space Administration (NASA), U.S. Department of Agriculture (USDA), DOC, and Department of Homeland Security (DHS). (Each of these agencies also conducts more than $1 billion of R&D annually through its intramural facilities or FFRDCs; see ▦ Table 4-16 in Chapter 4.) Technology transfer statistics for these agencies for FY 2014 (the latest data year available), with comparisons with FYs 2006, 2009, and 2012, appear in ▦ Table 8-3. (Similar statistics for a larger set of agencies, going back to FY 2001, appear in Appendix Table 8-27.) Consistent with the agencies' statutory annual reports, these statistics mainly cover the activity areas of invention disclosures and patenting, intellectual property licensing, and collaborative relationships for R&D.

TABLE 8-3

Federal laboratory technology transfer activity indicators, by selected agencies: FYs 2006, 2009, 2012, 2014

(Number of activities)

Fiscal year	Technology transfer activity	All federal laboratories	DOD	HHS	DOE	NASA	USDA	DOC	DHS
2014	Invention disclosures and patenting								
	Inventions disclosed	5,103	963	351	1,588	1,683	117	47	36
	Patent applications	2,609	916	216	1,144	146	119	25	5
	Patents issued	1,931	670	335	693	117	83	18	3
	Licensing								
	All licenses, total active in the fiscal year	20,822	527	1,555	5,861	2,381	414	41	10,313
	Invention licenses	3,956	425	1,186	1,560	253	363	41	2
	Other intellectual property licenses	16,866	102	369	4,301	2,128	51	0	10,311
	Collaborative relationships for R&D								
	CRADAs, total active in the fiscal year	9,180	2,762	532	704	0	267	2,359	158
	Traditional CRADAs	4,891	2,281	378	704	0	193	206	121
	Other collaborative R&D relationships	27,182	581	154	0	6,058	17,005	3,031	31
2012	Invention disclosures and patenting								
	Inventions disclosed	5,350	1,078	352	1,661	1,642	160	52	40
	Patent applications	2,361	1,013	233	780	131	122	21	10
	Patents issued	2,228	1,048	453	483	129	69	3	0
	Licensing								
	All licenses, total active in the fiscal year	11,452	520	1,465	5,328	3,013	384	41	523
	Invention licenses	3,882	432	1,090	1,428	284	341	41	0
	Other intellectual property licenses	7,660	88	375	3,900	2,729	43	0	523
	Collaborative relationships for R&D								
	CRADAs, total active in the fiscal year	8,307	2,400	377	742	0	274	2,410	94
	Traditional CRADAs	4,292	1,328	245	742	0	211	153	89

Fiscal year	Technology transfer activity	All federal laboratories	DOD	HHS	DOE	NASA	USDA	DOC	DHS
	Other collaborative R&D relationships	24,717	0	0	0	5,749	15,878	2,782	11
2009	Invention disclosures and patenting								
	Inventions disclosed	4,452	831	389	1,439	1,412	143	41	32
	Patent applications	1,957	690	156	775	141	123	20	2
	Patents issued	1,319	404	397	363	93	24	7	2
	Licensing								
	All licenses, total active in the fiscal year	12,598	432	1,584	5,742	4,181	330	40	63
	Invention licenses	3,854	386	1,304	1,452	146	302	40	45
	Other intellectual property licenses	8,744	46	280	4,290	4,035	28	0	18
	Collaborative relationships for R&D								
	CRADAs, total active in the fiscal year	7,756	2,870	457	744	1	259	2,397	23
	Traditional CRADAs	4,296	2,247	284	744	1	207	101	22
	Other collaborative R&D relationships	17,649	1	0	0	4,507	10,306	2,828	5
2006	Invention disclosures and patenting								
	Inventions disclosed	5,193	1,056	442	1,694	1,749	105	14	NA
	Patent applications	1,912	691	166	726	142	83	5	NA
	Patents issued	1,284	472	164	438	85	39	7	NA
	Licensing								
	All licenses, total active in the fiscal year	10,186	444	1,535	5,916	2,856	332	111	NA
	Invention licenses	4,163	438	1,213	1,420	308	332	111	NA
	Other intellectual property licenses	6,023	6	322	4,496	2,548	0	0	NA
	Collaborative relationships for R&D								
	CRADAs, total active in the fiscal year	7,268	2,999	164	631	1	195	3,008	NA
	Traditional CRADAs	3,666	2,424	92	631	1	163	149	NA
	Other collaborative R&D relationships	9,738	0	0	0	4,275	3,477	2,114	NA

NA = not available.

CRADA = Cooperative R&D Agreement; DHS = Department of Homeland Security; DOC = Department of Commerce; DOD = Department of Defense; DOE = Department of Energy; HHS = Department of Health and Human Services; NASA = National Aeronautics and Space Administration; USDA = Department of Agriculture.

Note(s)

The table includes seven federal departments and agencies that reported R&D obligations at or above $1 billion in FY 2014. (The National Science Foundation was also in this group, but its corresponding data were not available.) Other federal agencies not listed but included in the All federal laboratories totals are the Department of the Interior, Department of Transportation, Department of Veterans Affairs, and Environmental Protection Agency. Invention licenses refer to inventions that are patented or could be patented. Other intellectual property refers to intellectual property protected through mechanisms other than a patent (e.g., copyright). CRADAs refers to all agreements executed under CRADA authority (15 U.S.C. 3710a). Traditional CRADAs are collaborative R&D partnerships between a federal laboratory and one or more nonfederal organizations. Federal agencies have varying authorities for other kinds of collaborative R&D relationships.

Source(s)

National Institute of Standards and Technology, U.S. Department of Commerce, *Federal Laboratory Technology Transfer, Fiscal Year 2014: Summary Report to the President and the Congress* (2016), https://www.nist.gov/sites/default/files/documents/2016/10/26/fy2014_federal_tech_transfer_report.pdf. See Appendix Table 4-30.

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As the distribution of the statistics across the activity types in ▦ Table 8-3 shows, most of these agencies engage in all the transfer activity types to some degree—although the emphases differ. Some agencies (e.g., DOD, DOE, HHS) are particularly intensive in patenting and licensing activities; others (e.g., DOC, NASA, USDA) are intensive on transfer through collaborative R&D relationships. Furthermore, some agencies have unique transfer authorities (statutory) that can confer practical advantages. NASA, for example, can establish collaborative R&D relationships through special authorities it has under the National Aeronautics and Space Act of 1958; USDA has several special authorities for establishing R&D collaborations other than cooperative research and development agreements; DOE has contractor-operated national laboratories, with nonfederal staff, that are not constrained by the normal federal limitation on copyright by federal employees and can use copyright to protect and transfer computer software. In general, the mix of technology transfer activities pursued by each agency reflects a broad range of considerations such as agency mission priorities, the technologies principally targeted for development, the intellectual property protection tools and policies available, and the types of external parties through which transfer and collaboration are chiefly pursued.

The data for the most recent years in this series (FYs 2012–14) indicate that federal agency laboratories and FFRDCs as a group put forth some 5,100–5,400 invention disclosures annually, 2,400–2,600 patent applications, and receive 1,900–2,200 patent awards. These numbers have generally grown over the years, which is more apparent in the longer time series of data available in Appendix Table 8-27.

Year to year, the intramural or FFRDC laboratories of DOE and DOD consistently account for the largest levels of invention disclosures, patent applications, and patent awards. For example, DOE reported 1,588 invention disclosures in FY 2014, 1,144 patent applications, and 693 patent awards; DOD reported 963 invention disclosures, 916 patent applications, and 670 patent awards (▦ Table 8-4). In contrast, HHS, which is also one of the largest intramural or FFRDC R&D performers, reported 351 invention disclosures in FY 2014, 216 patent applications, and 335 patent awards. Further, NASA reported a high number of invention disclosures in FY 2014 but had low levels of patent applications and awards (146 and 117, respectively). This emphasizes that care must be used in comparing the track of these invention indicators over time and across agencies. Depending on the technologies involved, application areas, type of external development partners, and technology transfer authorities available—all of which vary across the federal government—the priority of attention to patenting as a main mechanism for promoting the transfer and downstream commercial development of federal laboratory inventions can differ among the agencies.

TABLE 8-4

Invention disclosures and patenting, by selected U.S. agencies with federal laboratories: FYs 2006–14

(Number)

Invention disclosures and patenting	2006	2007	2008	2009	2010	2011	2012	2013	2014
All 11 agencies[a]									
Inventions disclosed	5,193	4,486	4,572	4,452	4,755	5,251	5,350	5,321	5,103
Patent applications filed	1,912	1,825	1,952	1,957	2,002	2,308	2,361	2,494	2,609
Patents issued	1,284	1,405	1,253	1,319	1,468	1,449	2,228	1,855	1,931
DOD									
Inventions disclosed	1,056	838	1,018	831	698	929	1,078	1,032	963
Patent applications filed	691	597	590	690	436	844	1,013	942	916
Patents issued	472	425	462	404	304	523	1,048	648	670
HHS									
Inventions disclosed	442	447	437	389	337	351	352	320	351
Patent applications filed	166	261	164	156	291	272	233	230	216
Patents issued	164	379	278	397	470	270	453	428	335
DOE									
Inventions disclosed	1,694	1,575	1,460	1,439	1,616	1,820	1,661	1,796	1,588
Patent applications filed	726	693	904	775	965	868	780	944	1,144
Patents issued	438	441	370	363	480	460	483	554	693
NASA									
Inventions disclosed	1,749	1,514	1,324	1,412	1,735	1,723	1,642	1,618	1,683
Patent applications filed	142	127	122	141	150	130	131	146	146
Patents issued	85	68	90	93	130	111	129	116	117
USDA									
Inventions disclosed	105	126	100	143	149	158	160	191	117
Patent applications filed	83	114	123	123	113	124	122	157	119
Patents issued	39	37	30	24	45	49	69	65	83

Invention disclosures and patenting	2006	2007	2008	2009	2010	2011	2012	2013	2014
DHS									
Inventions disclosed	NA	NA	10	32	7	38	40	20	36
Patent applications filed	NA	NA	0	2	2	12	10	4	5
Patents issued	NA	NA	1	2	1	0	0	4	3
DOC									
Inventions disclosed	14	32	40	41	31	26	52	41	47
Patent applications filed	5	8	21	20	20	17	21	26	25
Patents issued	7	3	3	7	12	16	13	16	18

NA = not available.

DHS = Department of Homeland Security; DOC = Department of Commerce; DOD = Department of Defense; DOE = Department of Energy; HHS = Department of Health and Human Services; NASA = National Aeronautics and Space Administration; USDA = Department of Agriculture.

[a] Includes the 11 federal departments and agencies that report annual statistics on the technology transfer activities of their federal laboratories (statutory under the Technology Transfer Commercialization Act of 2000). In addition to the 7 departments and agencies separately described above, the totals include the activities of the Environmental Protection Agency, Department of the Interior, Department of Transportation, and Department of Veterans Affairs.

Note(s)

The 7 departments and agencies tallied above each obligated $1.0 billion or more for intramural and affiliated federally funded research and development center R&D in FY 2014 (DOD, $22.2 billion; DOE, $8.6 billion; HHS, $7.3 billion; NASA, $3.2 billion; USDA, $1.5 billion; DHS, $1.4 billion; DOC, $1.1 billion). Data for earlier years and the full set of 11 departments and agencies are in Appendix Table 4-30.

Source(s)

National Institute of Standards and Technology, U.S. Department of Commerce, *Federal Laboratory Technology Transfer, Fiscal Year 2014: Summary Report to the President and the Congress* (2016), https://www.nist.gov/sites/default/files/documents/2016/10/26/fy2014_federal_tech_transfer_report.pdf.

Science and Engineering Indicators 2018

Sources of Economically Valuable Knowledge

Indicators of economically valuable knowledge reflect only a portion of the knowledge about S&T that is shared. Tacit knowledge, shared through person-to-person exchanges, spreads locally and across networks of people interested in similar topics. This can take place informally and in conferences, through paid consulting and other business services, and through institutions organized for sharing knowledge and technology.

Economically valuable knowledge also spreads through publicly and freely available records, such as scientific publications, patent records, and open-source software, as well as through use of intellectual property, such as licensing of patents, copyrights, software, and trade secrets. Such documents and records are codified, or in some way formalized for transmission between people.

A key feature of knowledge is that many can use it, and it can be used repeatedly without being exhausted. It can spread or spill over to users outside the institutions where the knowledge is created. The ability for knowledge to be reused and shared across users yields great potency in fueling further economic growth (Romer 1986, 1990; Lucas 1988).

Sources of knowledge used in invention and innovation include business R&D, university and nonprofit institution research, the work of federal laboratories, and the experiences of scientists, engineers, and inventors as they create and develop new and useful products and processes. For business product innovation in manufacturing, sources outside of internal R&D labs are pervasive. Arora, Cohen, and Walsh (2016) found that for U.S. manufacturing firms, 49% reported that the invention underlying their most important innovation was external to the firm (see sidebar 💬 Open Innovation).

SIDEBAR

Open Innovation

The “open” model of innovation (Chesbrough 2003) highlights activities of firms that find it less costly to acquire their inventions from outside sources than to generate them using their own internal research and development laboratories. These firms innovate and compete successfully by sourcing technological and innovative knowledge broadly. Firm survey evidence shows the importance of the invention sources of product innovation in manufacturing that are separate from internal R&D work. For about half of the respondents to American Competitiveness Survey (ACS), which surveyed manufacturing firms with product innovations, the invention underlying their most important innovation was external to the firm. The customer was the most frequent source, followed by suppliers, and then outside technology specialists. These technology specialists include contract R&D performers, independent inventors, and universities. The ACS also finds an important role for startups as the source of invention, with 13% of respondents identifying this source (Arora, Cohen, and Walsh 2016).

One explanation for the growth in external sources of innovation is that information and communications technologies (ICT) improvements allow external innovators to create complementary products, extending the reach of open innovation (Evans and Gawer 2016). These improvements include gains in instrumentation and computing power which increase the potential for innovation to be separated into subprocesses that different teams can accomplish. By diminishing the limitations posed by geographic barriers, digital platforms allow for exchanges between suppliers and customers and for the development of new products and services. Further, ICT can raise the value of external expertise in abstract knowledge, which can be applied broadly across many fields (Arora and Gambardella 1994).

Coauthorship of Peer-Reviewed Research with the Business Sector

Coauthorship provides a means by which economically valuable knowledge can flow through collaboration with other scientists and engineers to the business sector, leading to the development of new and improved products and processes. Although the great majority of peer-reviewed S&E publications are produced by universities (described in the Chapter 5 section Publication Output, by U.S. Sector), authors with business-sector affiliations produced more than 51,000 publications in 2016 (▦ Table 8-5), over 80% of which were coauthored with academic, government, or foreign researchers. Reflecting the importance of collaboration with academic researchers, almost half (49%) of all business publications were produced with authors from U.S. academic institutions. Government coauthors appear on 13% of all business publications, and foreign coauthors appear on more than a third of all business publications (35%).

TABLE 8-5

U.S. business-sector publications with other U.S. sectors and foreign institutions: 2016

(Number and percent)

Business-sector publications	Number	Percent
All publications	50,889	100.0
Total coauthored	41,485	81.5
Total coauthored with another U.S. sector (excluding business sector) and/ or foreign institution	37,268	73.2
Coauthored with another institution from business sector	8,408	16.5
Coauthored with another U.S. sector	28,321	55.7
Coauthored with academic sector	24,964	49.1
Coauthored with non-academic sector	9,857	19.4
Coauthored with government	6,587	12.9
Coauthored with private nonprofits and other	4,059	8.0
Coauthored with foreign institution	17,775	34.9

Note(s)

Article counts are from a selection of journals, books, and conference proceedings in S&E from Scopus. Articles are classified by their year of publication and are assigned to a sector on the basis of the institutional address(es) listed in the article. Articles are credited on a whole-count basis (i.e., each collaborating institution type is credited one count in each qualifying group). The sum of articles coauthored with various sectors could exceed the total number of articles coauthored with another sector and/or foreign sector due to articles coauthored by multiple sectors. Articles from unknown U.S. sectors are not shown. Counts of publications coauthored with another U.S. sector are limited to copublications involving the U.S. sector at stake and another different sector. For instance, the number of coauthored publications with a non-academic sector does not include publications coauthored with another institution from the U.S. business sector.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; U.S. Patent and Trademark Office; Elsevier, Scopus abstract and citation database (https://www.scopus.com/), accessed July 2017.

Science and Engineering Indicators 2018

Citations of S&E Articles and USPTO Patents

In addition to co-authorships, citations of S&E articles in patent documents provide indicators of economically-valuable knowledge as inputs to invention. Patent documents accessed from USPTO provide text citations to earlier patents issued (prior art) and to nonpatent literature (NPL), which includes peer-reviewed research and other published documents.

As an indicator of knowledge transfer, the linkages can be indirect. Earlier patents may be cited by the inventor to demonstrate their difference from prior art or added by the examiner to limit the scope of the patent (IEEE 2010). Citations to

NPL are considered stronger indicators of the impact of academic research on business patenting than citations to patents, though both miss flows from private and contract research, as well as flows from basic research (Roach and Cohen 2012).

Almost a quarter (23%) of USPTO patents issued in 2016 cite S&E articles (Table 8-6), with almost 300,000 S&E articles cited. Six fields of science accounted for nearly all (98%) of the citations in USPTO patents granted in 2016 (Appendix Table 8-28). Biological sciences make up the largest share (34%), followed by medical sciences (24%), computer sciences (12%), engineering (11%), chemistry (9%), and physics (8%) (Figure 8-11).

TABLE 8-6

U.S. utility patents citing S&E literature, by patent assignee sector, article author sector, and patent issue year: 2013–16

(Number)

Patent assignee sector and article author sector	2013	2014	2015	2016
USPTO utility patents				
All utility patents	278,517	301,643	299,382	304,126
Patents citing S&E literature, all assignee sectors	64,572	70,124	68,761	69,025
Foreign	24,641	26,902	26,664	26,941
Unknown country	92	93	91	107
United States	39,839	43,129	42,006	41,977
Government	716	751	719	695
Private	33,354	36,161	35,004	34,688
Academic	4,334	4,700	4,844	5,176
Other	324	326	337	301
Individuals	1,106	1,149	1,035	1,073
No information on organization or unclassified	7	42	67	44
S&E articles				
All S&E articles, all article author sectors	14,210,554	15,085,104	16,048,163	17,069,262
All cited S&E articles, all article author sectors	274,312	290,951	288,922	290,433
Foreign	150,246	160,215	161,203	163,365
Unknown country	1,469	1,477	1,313	1,259
United States	122,597	129,259	126,407	125,809
Federal government	5,979	6,138	6,001	5,849
Industry	20,385	21,103	19,890	18,919
Academic	81,736	86,965	85,996	86,797
FFRDCs	2,425	2,651	2,580	2,637
Nonprofit	6,635	6,843	6,782	6,510
State and local government	153	138	137	165

Patent assignee sector and article author sector	2013	2014	2015	2016
Joint or unknown sectors	5,285	5,421	5,020	4,932
Citations from USPTO utility patents to S&E articles				
All citations, all article author sectors	582,179	640,922	633,407	615,028
Foreign	301,659	336,684	337,309	329,291
Unknown country	3,098	3,232	2,913	2,744
United States	277,423	301,006	293,185	282,993
Federal government	11,738	12,428	12,114	11,396
Industry	51,465	56,946	52,842	49,392
Academic	181,090	195,796	193,748	189,995
FFRDCs	5,476	6,011	5,644	5,562
Nonprofit	14,893	16,213	16,367	15,195
State and local government	296	309	269	333
Joint or unknown sectors	12,466	13,304	12,199	11,119

FFRDC = federally funded research and development center; USPTO = U.S. Patent and Trademark Office.

Note(s)

Article and citation counts are from the set of journals covered by Scopus. Articles are assigned to a sector on the basis of the institutional address(es) listed in the article. Articles and citations are credited on a fractional-count basis (i.e., for articles with collaborating institutions from multiple sectors, each sector receives fractional credit on the basis of the proportion of its participating institutions). Citation counts are based on an 11-year window with a 5-year lag (e.g., citations for 2012 are references in U.S. patents issued in 2012 to articles published in 1997–2007). Article counts are a sum of articles in the cited-year window. Detail may not add to total because of rounding. Data in the table are not comparable to previous versions due to changes in the cited-year window.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; PatentsView and USPTO data; Elsevier, Scopus abstract and citation database (https://www.scopus.com/), accessed April 2017 (patent data) and July 2017.

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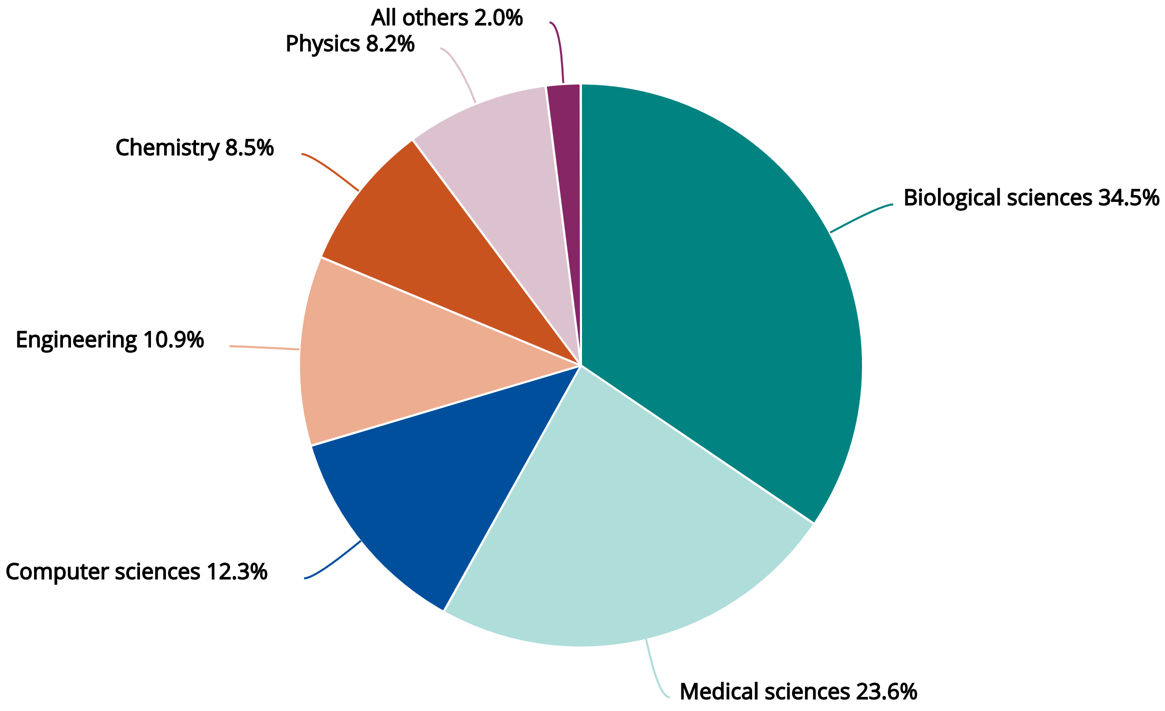
FIGURE 8-11

Citations of U.S. S&E articles in U.S. patents, by selected S&E article field: 2016



Source(s)

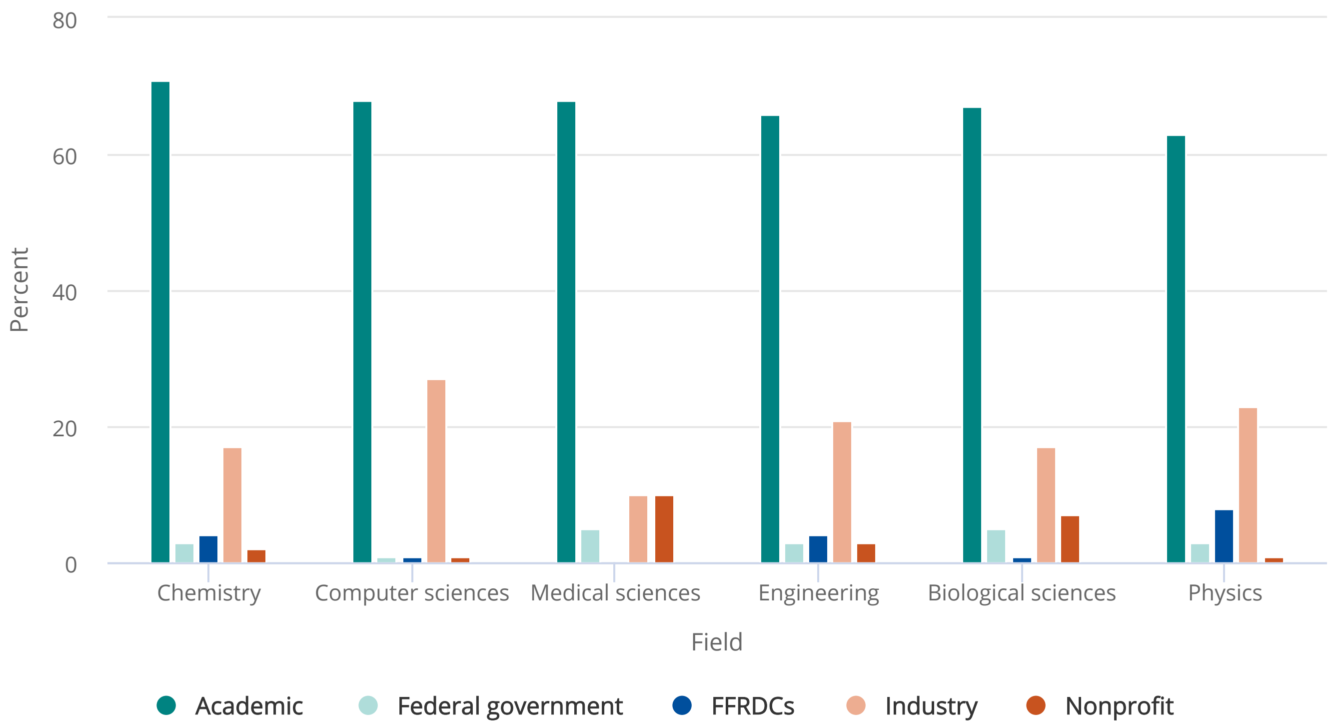
National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; PatentsView; U.S. Patent and Trademark Office patent data; Elsevier, Scopus abstract and citation database (https://www.scopus.com/), accessed April 2017 (patent data) and July 2017. See Appendix Table 8-28.

Science and Engineering Indicators 2018

Across fields, the authors of most cited S&E literature in patent documents are from the academic sector. Consistent with its large share of S&E publications and citations overall, the U.S. academic sector received 31% of NPL citations from all USPTO patents in 2016 and 67% of citations from patents granted to U.S. patent owners. Within fields of science, industry publications receive 20% or more of the patent citations in computer sciences, engineering, and physics (Figure 8-12). Articles from other nonacademic sectors receive far fewer citations in patents, but this varies by field. After academia, industry articles capture the next largest share of citations overall, with particularly high citations in computer sciences (27%), physics (23%), and engineering (21%). In medical sciences, industry and nonprofit articles each account for 10% of patent citations. Compared with other fields, federal government S&E articles receive the largest number of citations in biological and medical sciences (each 5%), and FFRDCs receive the largest number of citations in physics (8%).

FIGURE 8-12

Citation of U.S. S&E articles in USPTO patents, by selected S&E field and article author sector: 2016



FFRDC = federally funded research and development center.

Note(s)

Fields with less than 5% in 2016 are omitted. Citations where the sector is unknown sectors are not shown. Citations to state and local government S&E articles are also not shown.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; PatentsView; U.S. Patent and Trademark Office patent data; Elsevier, Scopus abstract and citation database (https://www.scopus.com/), accessed April 2017 (patent data) and July 2017 (S&E articles data). See Appendix Table 8-28.

Science and Engineering Indicators 2018

The globalization of USPTO patents is reflected in the foreign sources of cited articles and in the foreign share of USPTO patents described earlier, in the section USPTO Patenting Activity. In 2016 foreign articles drew more citations in USPTO patents (54%) than U.S. articles (46%) (Table 8-6).

Global Flows of Payments for Intellectual Property: Trade in Licensing and Fees

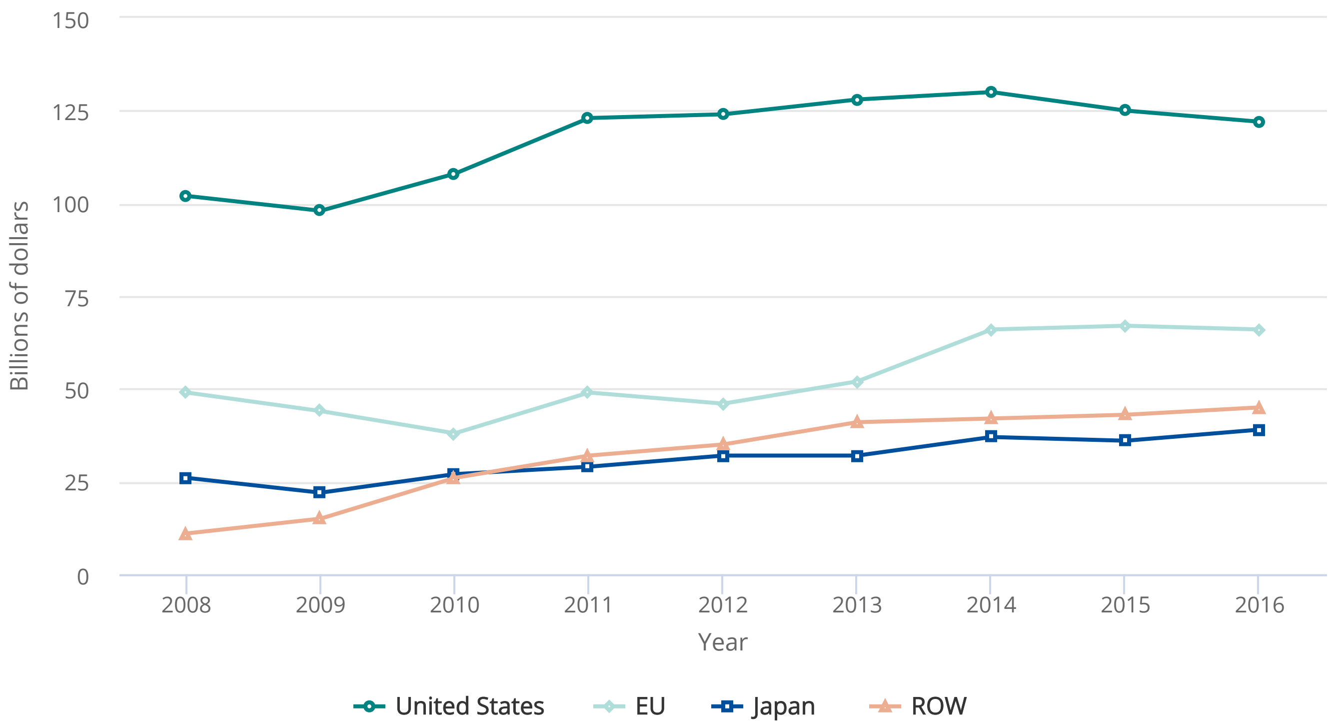
Licensing allows intellectual property developed within firms to be used externally and globally active businesses transfer their intellectual property across national boundaries, exploiting opportunities in external markets. This intellectual property includes the use of proprietary rights—patents, trademarks, copyrights, industrial processes, and designs—and licenses to reproduce and/or distribute intellectual property embodied in produced originals, prototypes, live performances, and televised broadcasts (World Trade Organization 2016).

The export revenues for these types of transactions, known as "charges for the use of intellectual property," provide a broad indicator of technology flows across the global economy and the value of an economy's intellectual property in the international marketplace.[2] Receipts from other countries for this trade provide a partial measure of market-based income for the use of intellectual property. International receipts for the use of intellectual property also represent global exports of services, playing an important role in understanding the global balance of trade. However, such receipts are a partial indicator of these flows. The volume and geographic patterns of U.S. trade in royalties and fees have been influenced by U.S.-based multinational companies transferring their intellectual property to low-tax jurisdictions or their foreign subsidiaries to reduce their U.S. and foreign taxes (Gravelle 2010:8; Mutti and Grubert 2007:112).

Global exports (receipts for the use of intellectual property) were $272 billion in 2016 (Appendix Table 8-29). The United States was the world's largest exporter (45% global share) with a substantial trade surplus (Figure 8-13).[3] However, over several years the U.S. global share has fallen from 54% in 2008 to 45% in 2016.

FIGURE 8-13

Exports of intellectual property (charges for their use), by selected region, country, or economy: 2008–16



EU = European Union.

Note(s)

EU exports do not include intra-EU exports.

Source(s)

World Trade Organization, Trade and tariff data, https://www.wto.org/english/res_e/statis_e/statis_e.htm, accessed 15 September 2017.

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The EU is the second largest, with a global export share of 24%, but it has a substantial deficit. After falling from 26% to 20% between 2008 and 2012, the EU share rose to reach 24% between 2013 and 2016. Japan, the third largest (14% share), has a substantial trade surplus. Japan's global export share has remained stable between 2008 and 2016. For developing countries, receipts for the use of intellectual property are very low; for example, the global export shares of China and India were less than 0.5% in 2016 (Appendix Table 8-29).

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[1] Data on technology transfer metrics such as these are now increasingly available. Nonetheless, the federal technology transfer community has long recognized that counts of patent applications and awards, intellectual property licenses, cooperative research and development agreements, and the like do not usually of themselves provide a reasonable gauge of the downstream outcomes and impacts that eventually result from transfers—many of which involve considerable time and

many subsequent developments to reach full fruition. Literature on federal technology transfer success stories is growing, facilitated in part by the annual agency technology transfer performance reporting mandated by the Technology Transfer Commercialization Act of 2000 and through regularly updated reports by technology transfer professional organizations such as the Federal Laboratory Consortium for Technology Transfer (FLC). (For an ongoing, but selective, accounting of federal laboratory technology transfer success stories, organized by the FLC, see the “Success Stories” map in FLC [2017].) Even so, the documentation of these downstream outcomes and impacts remains well short of being complete.

[2] Differences in tax policies and protection of intellectual property also likely influence the volume and geographic patterns of global trade in royalties and fees (Gravelle 2010:8; Mutti and Grubert 2007:112).

[3] The volume and geographic patterns of U.S. trade in royalties and fees have been influenced by U.S.-based multinational companies transferring their intellectual property to low-tax jurisdictions or their foreign subsidiaries to reduce their U.S. and foreign taxes (Gravelle 2010:8; Mutti and Grubert 2007:112).

Innovation Indicators: United States and Other Major Economies

Inventions and knowledge transfer are two activities that provide the raw material for commercially viable, new, and improved products and processes. Indicators in this section focus more directly on ways these inputs create new value in the economy. This includes business investment in intangibles, such as software, R&D and artistic creations, private funding of innovation, government policies and programs intended to facilitate innovation, and firm-reported data on the introduction of new and improved products and processes. The chapter closes with indicators of economic impacts of innovation in the form of increased productivity, the creation of new firms, and the employment that results from these new firms.

Investment in Intangibles

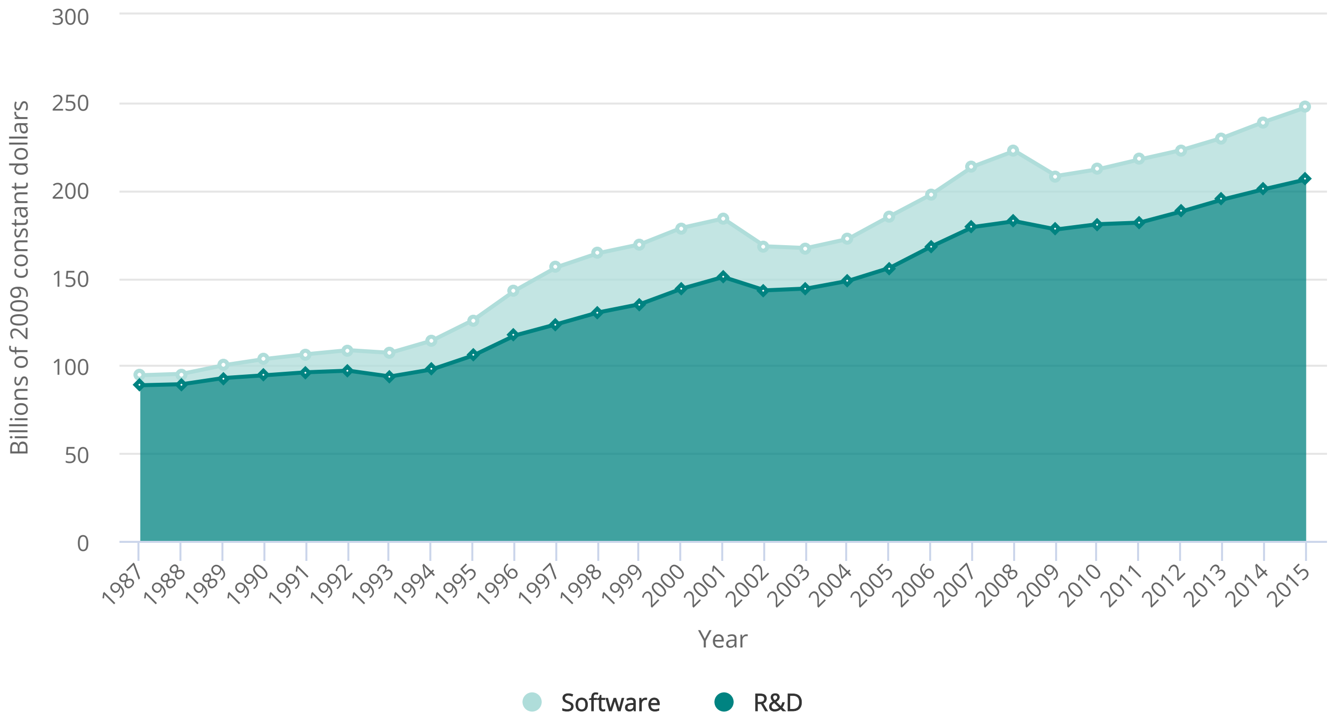
Intangibles in the economy include many services, such as insurance, education, telecommunications, as well as experiences such as concerts, movies, and sporting events; brand images; and embedded technology, such as software in cars and nutritionally enhanced food products (Blair and Wallman 2001).

Some intangibles once created provide benefits for years to come, for example computer software, R&D activity, designs and artistic creations. Often they can be simultaneously in more than one location, adding a dimension of use that tangibles do not possess. Digitization also allows many types of intangibles to be transmitted digitally across networks, multiplying potential impact further.

Gross domestic product (GDP) statistics for many countries, including the United States, include investment measures for the following types of intangible capital: computer software and databases, R&D expenditures, and artistic originals. Artistic originals are long-lived artwork produced by artists, studios, and publishers, including music, books, and programming, as measured by the Bureau of Economic Analysis (BEA) (Soloveichik and Wasshausen 2013) and tabulated by the U.S. Bureau of Labor Statistics as part of its measurement of productivity. Figure 8-14 and Figure 8-15 show investment for the U.S. manufacturing sector and for the nonfarm, nonmanufacturing sector in computer software, R&D, and artistic originals, adjusted for inflation with 2009 as the base year. The data are based on the categories used in the national income accounts. To prevent double counting in these measures, R&D directed toward the creation of computer software is categorized with computer software rather than with R&D (BEA 2013).

FIGURE 8-14

Private investment in intangibles, by type, for the manufacturing sector: 1987–2015



Note(s)

Investment in artistic originals is not estimated for manufacturing.

Source(s)

Bureau of Labor Statistics, Intellectual Property Products, Private Business Sector, https://www.bls.gov/mfp/mprdload.htm#CapitalTables, accessed 30 August 2017.

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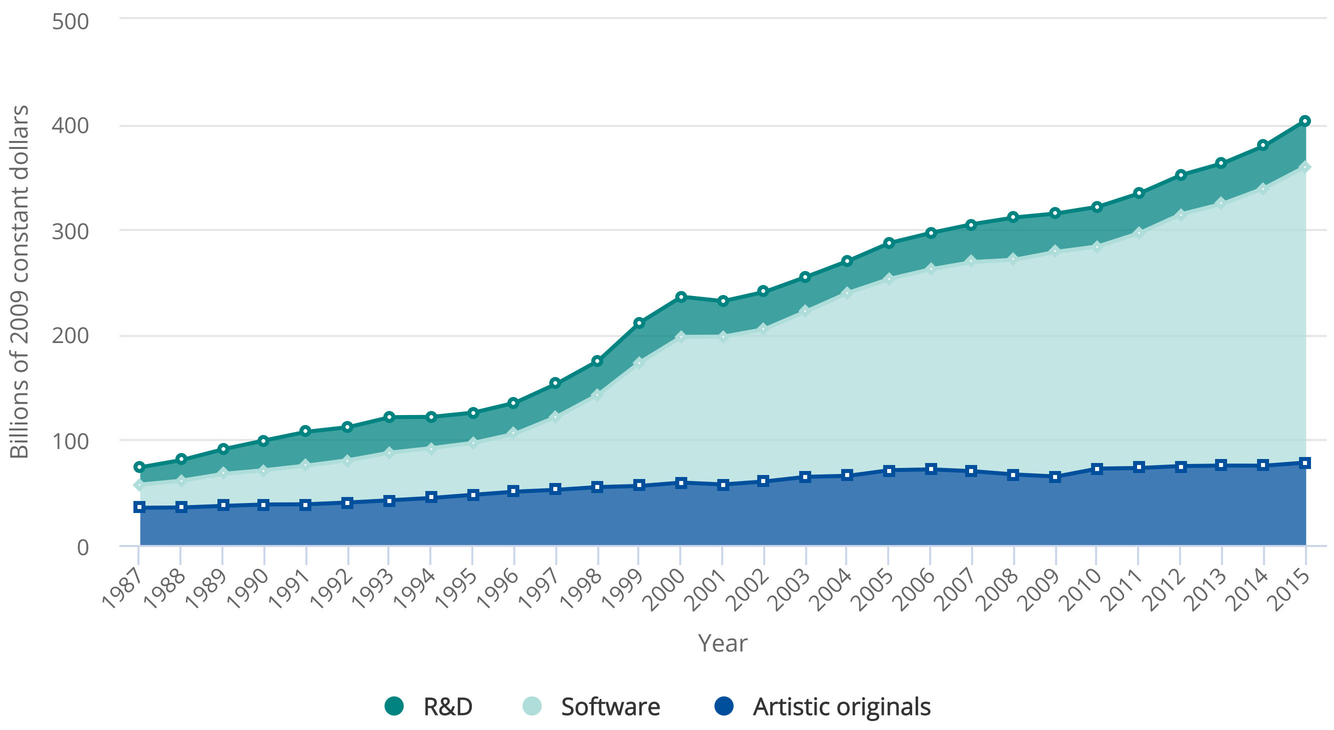
FIGURE 8-15

Private investment in intangibles, by type, for the nonmanufacturing sector: 1987–2015



Note(s)

Measured in 2009 constant dollars, farm sector is not included in these measures.

Source(s)

Bureau of Labor Statistics, Intellectual Property Products, Private Business Sector,

https://www.bls.gov/mfp/mprdload.htm#CapitalTables, accessed 30 August 2017.

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Outside of manufacturing, the relative magnitudes of R&D and computer software investment differ and software investment comprises a much larger share of overall investment in intangibles. In the nonmanufacturing sector, investment in computer software in 2015 ($282 billion) is more than six times as large as that of the manufacturing sector ($41 billion) (Figure 8-15). Additionally, investment in artistic originals is considerably larger than in R&D. In 2015, investment in these artistic originals was $78 billion. Digitization and networking allow these originals to be transformed into downloadable and streaming services; such services are increasingly consumed using personal devices such as laptops, tablets, and cell phones.

The indicators presented cover important, but not all, types of intangible capital. Some firm investments are in the human capital embedded in people. Formal investments in education, training, and health; and experience gained through on-the-job training and other activities may be not only capital for the individual but also for the firm. A broader perspective on intangible capital suggests that all investments in intangibles that firms use repeatedly over time should be treated as capital assets. Other types of activities that could be included as intangible capital include spending on designs, spending to develop and protect brands, spending to develop human capital in the firm, and spending devoted to organizational development (Corrado, Hulten, and Sichel 2005, 2007).

Venture Capital

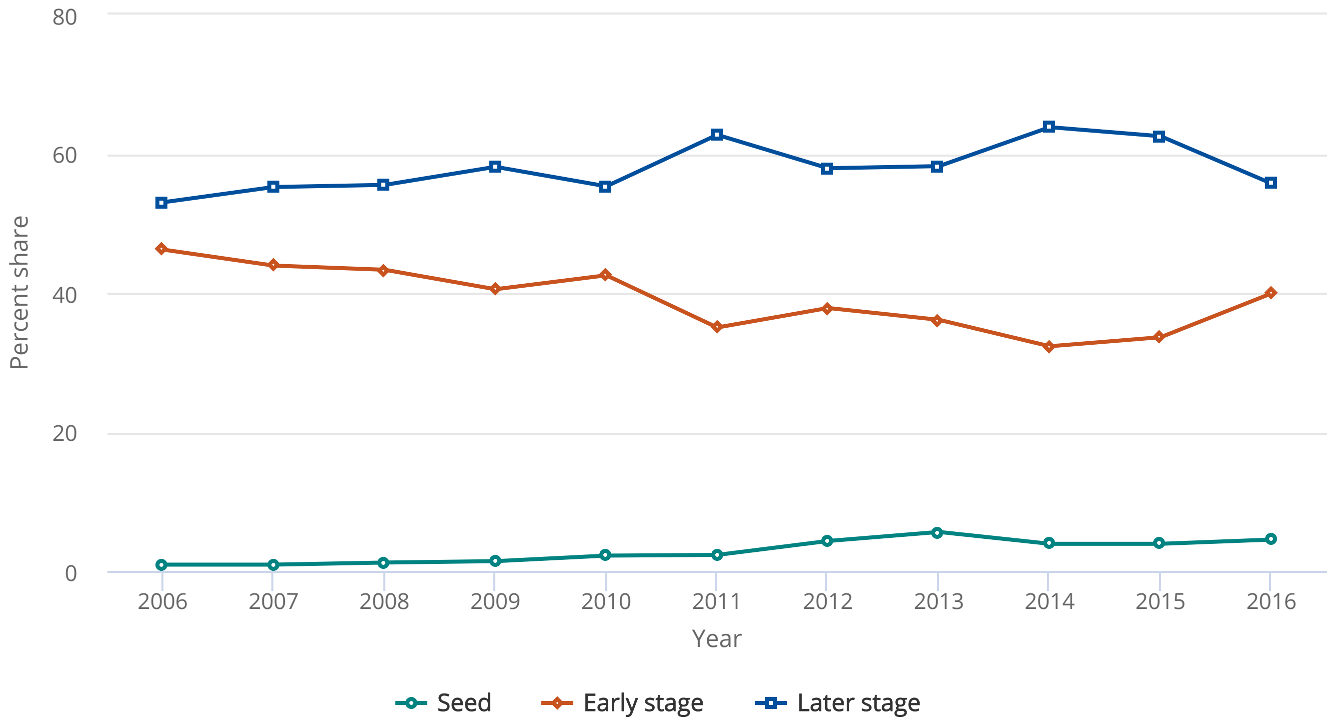
Access to financing is an essential component of the translation of inventions to innovations. Entrepreneurs seeking to start a new firm to commercialize a nascent or emerging technology rely on several funding sources: the entrepreneur's own funds, friends and family, bank loans, venture capital, angel investment, and government support (OECD 2014:174). Patterns and trends in venture capital investment are an indicator of support for emerging technologies that could make their way into the economy or are increasing their use in the economy. Venture capital investment is also an important financing source for existing high-technology firms that are commercializing technology. This section uses data from PitchBook, a company that collects comprehensive global data on venture capital and other early-stage investment.

Venture capital investment is generally categorized into three broad stages of financing—seed stage, early stage, and later stage. Seed-stage financing supports proof-of-concept development and initial product development and marketing and is important for understanding emerging technology trends. Global seed-stage venture capital investment was $6 billion in 2016, accounting for a very small share (4%) of total venture capital investment (Figure 8-16; Appendix Table 8-30). Early-stage financing accounted for 40% ($52 billion) of total venture capital investment in 2016. Early-stage financing supports product development and marketing and the initiation of commercial manufacturing and sales (Figure 8-16; Appendix Table 8-30); it also supports company expansion and provides financing to prepare for an initial public offering (IPO). Later-stage financing accounted for 56% ($73 billion in 2016) of total venture capital financing. Later-stage financing includes acquisition financing and management and leveraged buyouts. Acquisition financing provides resources for the purchase of another company, and management and leveraged buyouts provide funds to enable operating management to acquire a product line or business from a public or a private company.

Venture capital has been highly concentrated in early- and later-stage financing over the last decade and a half (Figure 8-16). The limited amount of seed-stage financing has been attributed to the reluctance of venture capitalists to invest in the uncertain and risky state of new product development (World Bank 2010:90). The difficulty of entrepreneurs obtaining seed-stage financing contributes to the "valley of death," the inability of new and nascent firms to obtain financing to commercialize their inventions and technology (OECD 2014:174).

FIGURE 8-16

Global venture capital investment, by financing stage: 2006–16



Note(s)

Venture capital investment does not include pre-incubator, accelerator, or angel investment. Seed financing supports proof-of-concept development and initial product development and marketing. Early-stage financing supports product development and marketing, the initiation of commercial manufacturing, and sales; it also supports company expansion and provides financing to prepare for an initial public offering. Later-stage financing includes acquisition financing and management and leveraged buyouts.

Source(s)

PitchBook, venture capital and private equity database, https://my.pitchbook.com/.

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Seed-Stage Venture Capital Investment

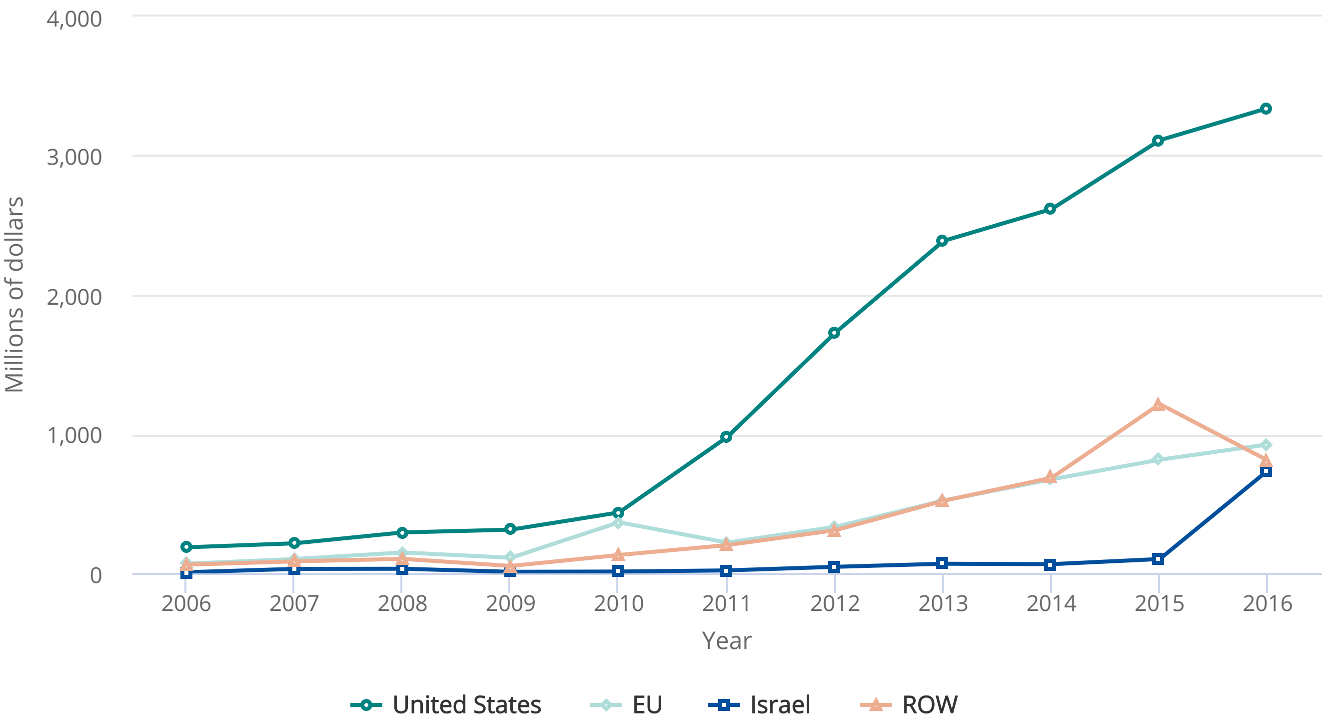
Global seed-stage venture capital investment was $5.8 billion in 2016 (Figure 8-17; Appendix Table 8-30). The United States received $3.3 billion, the largest share (58%) by far of any region or country. The EU and Israel were the second and third largest recipients, receiving $0.9 billion and $0.7 billion, respectively.

Global seed-stage investment has grown exponentially over the last decade, from more than $300 million in 2006 to $5.8 billion in 2016 (Figure 8-17 and Figure 8-18; Appendix Table 8-30); its growth rate (34% annualized average rate) was more than double that of early- and later-stage investment (13% annualized average rate), resulting in the seed-stage share of total investment increasing from 1% to 4% (Figure 8-18). Despite its strong growth over the last decade, seed stage remains a very small share of total venture capital investment.

In the United States, seed-stage financing grew from less than $200 million in 2006 to $3.3 billion in 2016 (Figure 8-17; Appendix Table 8-30). Like global trends, it grew far more rapidly (34% annualized average) than total U.S. early- and later-stage investment (9% annualized average).

FIGURE 8-17

Seed-stage venture capital investment, by selected country or economy: 2006–16



EU = European Union; ROW = rest of world.

Note(s)

Seed-stage venture capital financing supports proof-of-concept development and initial product development and marketing for startups and small firms that are developing new technologies. EU consists of present 28 member countries.

Source(s)

PitchBook, venture capital and private equity database, https://my.pitchbook.com/.

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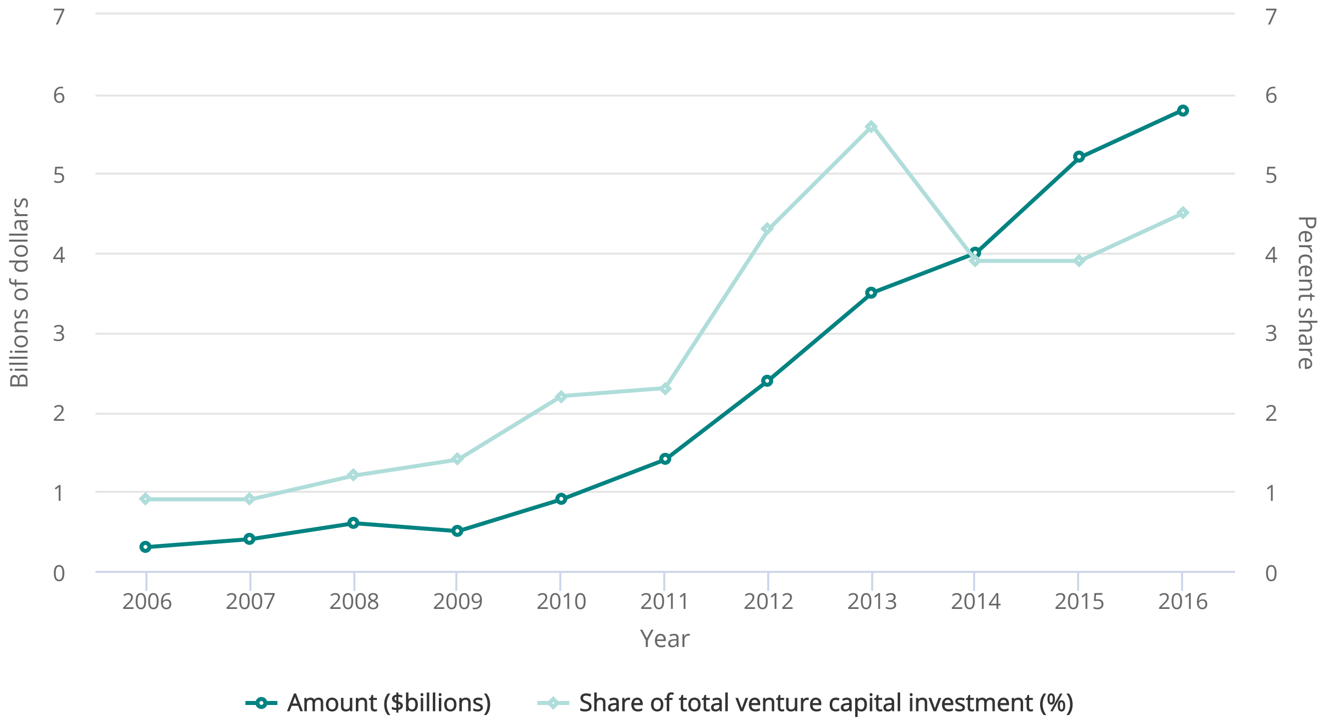
FIGURE 8-18

Global seed-stage venture capital investment: 2006–16



Note(s)

Seed-stage financing supports proof-of-concept development and initial product development and marketing for startups and small firms that are developing new technologies.

Source(s)

PitchBook, venture capital and private equity database, https://my.pitchbook.com/.

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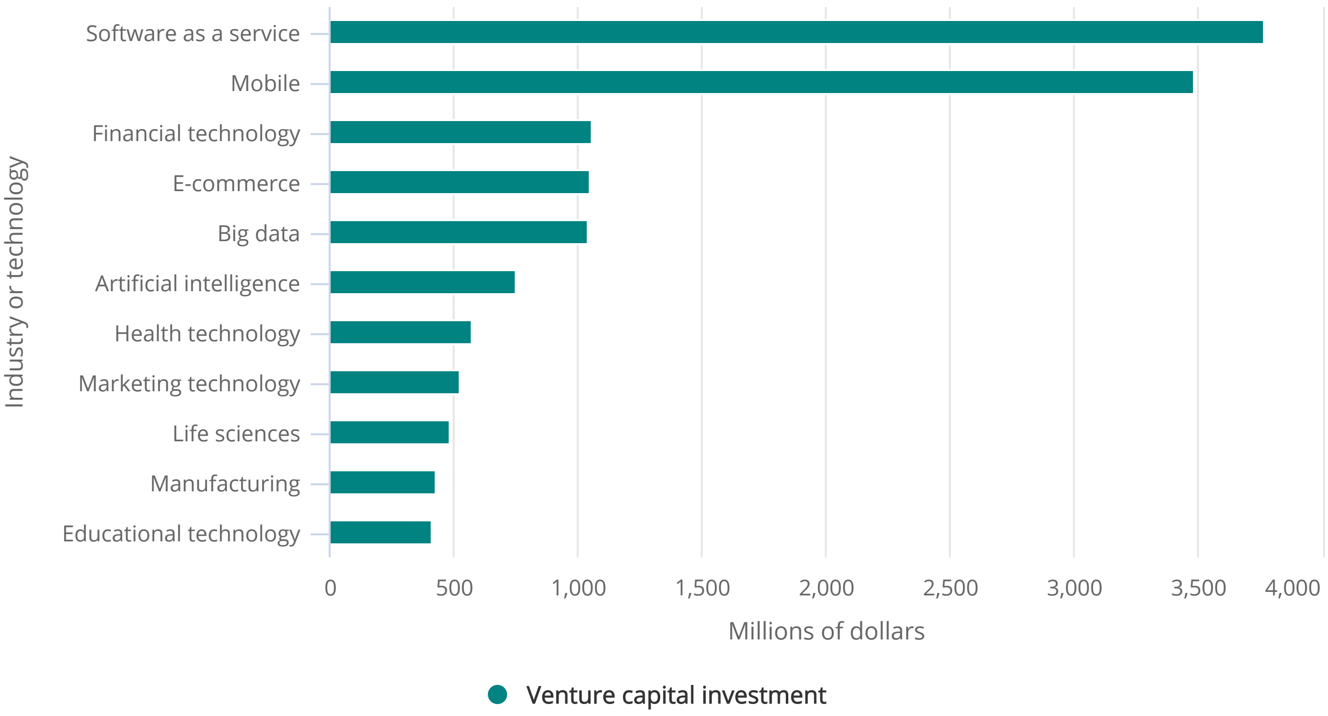
U.S. seed-stage venture capital investment by industry

PitchBook classifies firms that receive venture capital investment by industry (Appendix Table 8-31). Venture capital-backed firms that operate in multiple industries are classified in multiple industries. Classifying firms in multiple industries gives a more comprehensive picture compared with single industry classification because many firms produce products and services in multiple and diverse industries. The disadvantage is that the sum of venture capital investment in multiple industries exceeds total investment because of the double counting of investment in companies that are classified in multiple industries.

Between 2011 and 2016, the two industries that received the largest amount of seed-stage investment were software as a service ($3.8 billion) and mobile ($3.5 billion) (Figure 8-19; Appendix Table 8-32). Industries that received between $0.8 billion and $1.1 billion were financial technology, e-commerce, big data, and artificial intelligence. (Big data consist of companies that provide a product or service that is too large for traditional database systems.) Artificial intelligence, consisting of a variety of technologies, including software, natural language processing, and optical character recognition technology that has close ties to science, received $0.8 billion. Life sciences, a technology that is also closely tied to basic research in biotechnology and pharmaceuticals, received $0.5 billion.

FIGURE 8-19

U.S. seed-stage venture capital investment, by selected industry: 2011–16



Note(s)

Seed-stage financing supports proof-of-concept development and initial product development and marketing for startups and small firms that are developing new technologies. Industries ranked by the sum of investment between 2011 and 2016. Firms that receive venture capital investment are classified by industry. The sum of investment in industies exceeds total investment because firms that have activities in multiple industries are classified in multiple industries.

Source(s)

PitchBook, venture capital and private equity database, https://my.pitchbook.com/.

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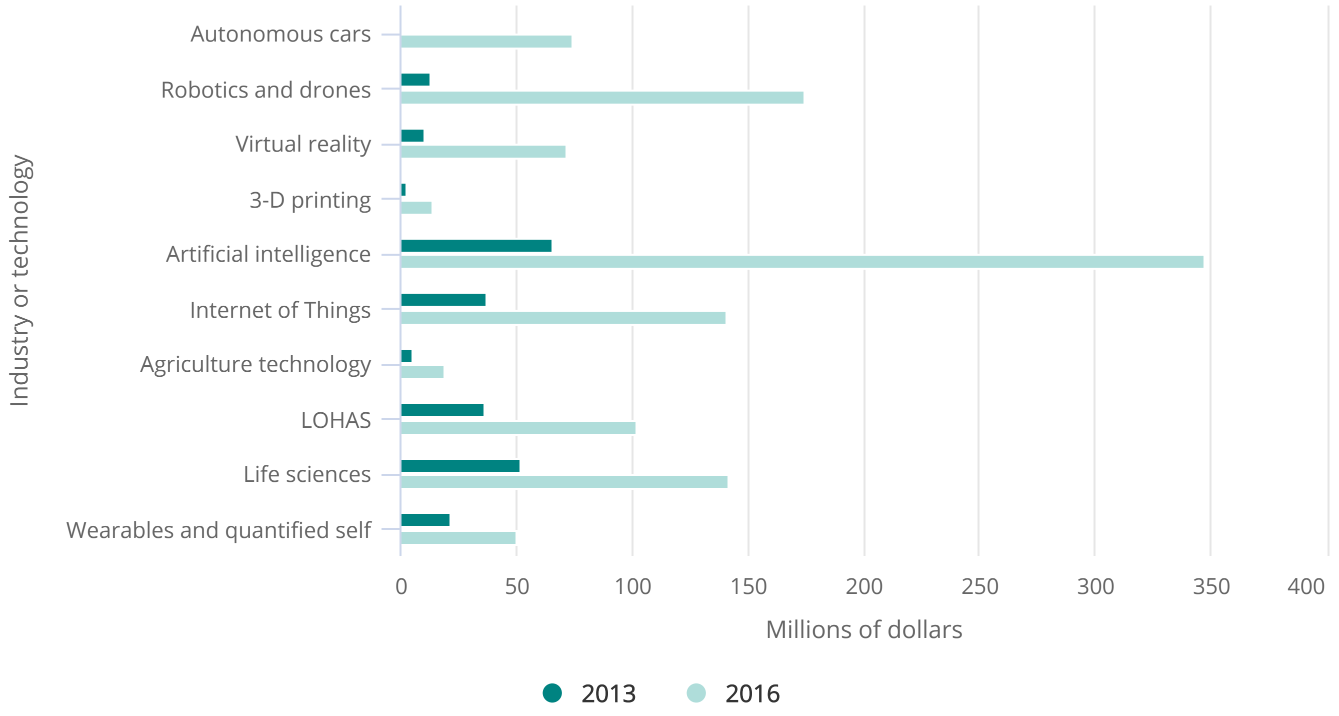
Industries that have rapid increases in seed-stage investment may indicate nascent or emerging technologies. Investment in autonomous cars went from zero in 2013 to $74 million in 2016 (Figure 8-20; Appendix Table 8-32). Investment in the early- and later stages also grew very rapidly in this industry (Figure 8-21). (See the discussion in section U.S. early- and later-stage venture capital investment by industry.) Robotics and drones had the largest increase from 2013 to 2016 in investment (139% annualized average rate), reaching $175 million in 2016. Investment in virtual reality grew at a 91% annualized average rate to reach $72 million; early- and later-stage investment also rapidly increased (Figure 8-21). Artificial intelligence grew by a 74% annualized average rate between 2013 and 2016 to reach $347 million, the highest level of investment among fast-growing industries in 2016. Investment in the Internet of Things was robust (56% annualized average rate), reaching $141 million. (See Chapter 6 sidebar The Internet of Things for a discussion of these technologies.) Investment in life sciences, an area that includes pharmaceuticals and biotechnology that is closely linked to basic science, grew more slowly (39% annualized average rate between 2013 and 2016), also reaching $141 million.

FIGURE 8-20

U.S. seed-stage venture capital investment, by selected industry: 2013 and 2016



LOHAS = lifestyles of health and sustainability.

Note(s)

Quantified self is the use of technology to collect data about one's self. Seed-stage financing supports proof-of-concept development and initial product development and marketing for startups and small firms that are developing new technologies. Venture capital investments in firms are classified into industry verticals. The sum of investment in industry verticals exceeds total investment because firms that have activities in multiple industries are classified in multiple industries. Industries ranked by the largest increase in investment between 2013 and 2016.

Source(s)

PitchBook, venture capital and private equity database, https://my.pitchbook.com/.

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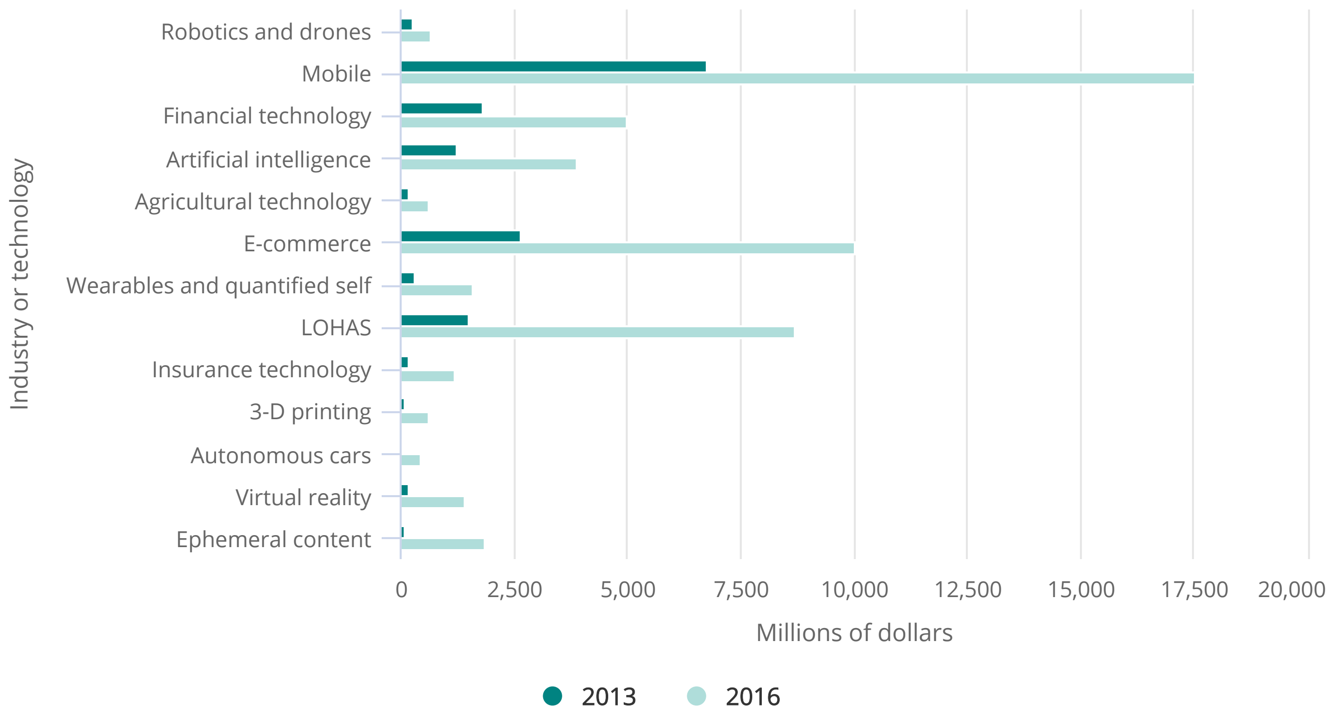
FIGURE 8-21

U.S. early- and later-stage venture capital investment, by selected industry: 2013 and 2016



LOHAS = lifestyles of health and sustainability.

Note(s)

Quantified self is the use of technology to collect data about one's self. Early-stage financing supports product development and marketing, the initiation of commercial manufacturing, and sales; it also supports company expansion and provides financing to prepare for an initial public offering. Later-stage financing includes acquisition financing and management and leveraged buyouts. Venture capital investments in firms are classified into industry verticals. The sum of investment in industry verticals exceeds total investment because firms that have activities in multiple industries or technologies are classified in multiple industry verticals. Industries ranked by the largest increase in investment between 2013 and 2016.

Source(s)

PitchBook, venture capital and private equity database, https://my.pitchbook.com/.

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Early- and Later-Stage Venture Capital Investment

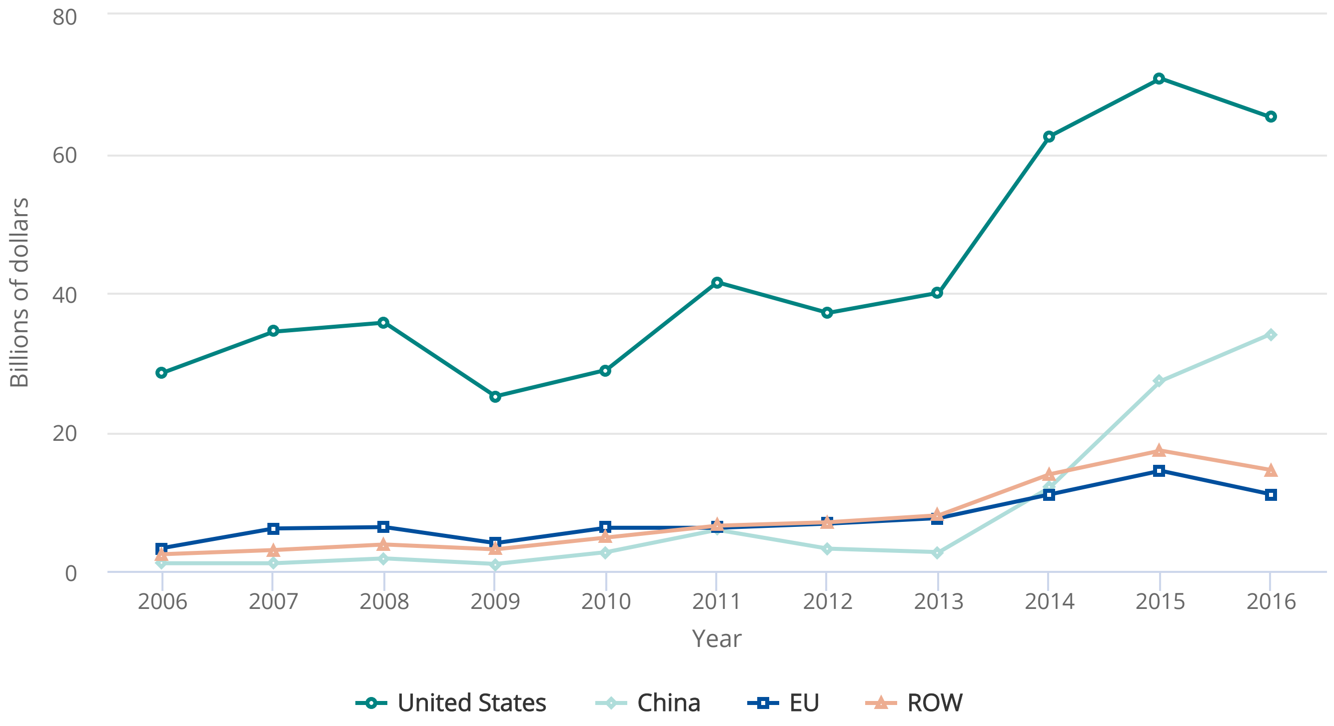
Global early- and later-stage venture capital investment was $125 billion in 2016 (Figure 8-22; Appendix Table 8-30). The United States attracted the most investment ($65 billion) of any region or country, accounting for slightly more than half of global investment. China attracted the second largest amount of investment ($34 billion) with a global share of 27%. The EU attracted the third largest amount ($11 billion).

Between 2006 and 2013, early- and later-stage global venture capital investment remained annually in the range of $30–$60 billion before surging to $99 billion in 2014 (Figure 8-22; Appendix Table 8-30). After increasing by 31% to $130 billion in 2015, investment fell slightly to $125 billion in 2016 because of high valuations of venture-backed companies, the lack of exits of existing venture-backed firms, and political and economic uncertainties (KPMG 2017:7).

Investment in China soared from $3 billion in 2013 to $34 billion in 2016, the largest increase of any country (Figure 8-22). China's share of global investment climbed from 5% in 2013 to 27% in 2016. The rise of China's middle class with disposable income and the government's focus on promoting domestic innovation have prompted major investments by private venture firms based in China and other countries, largely from the United States. The Chinese government has also created almost 800 public-backed venture capital funds that have raised more than $300 billion to invest in China (Oster and Chen 2016).

FIGURE 8-22

Early- and later-stage venture capital investment, by selected country or economy: 2006–16



EU = European Union; ROW = rest of world.

Note(s)

Early-stage financing supports product development and marketing, the initiation of commercial manufacturing, and sales; it also supports company expansion and provides financing to prepare for an initial public offering. Later-stage financing includes acquisition financing and management and leveraged buyouts.

Source(s)

PitchBook, venture capital and private equity database, https://my.pitchbook.com/.

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Early- and later-stage venture capital investment in the United States rose sharply (63%) to reach $65 billion between 2013 and 2016. Despite the robust growth in U.S. investment, the U.S. global share dropped from 69% in 2013 to 52% in 2016 due to more rapid growth in China. One factor that has driven the growth in U.S. investment is Chinese-based venture capital investors who have invested heavily in U.S. startups and venture-backed firms; one source estimates that about one-quarter of venture capital invested in the United States in 2015 originated from China (Oster and Chen 2016). China's growing wealth and the government's push to develop innovative high technologies have prompted Chinese-based companies and wealthy individuals to invest in U.S. startups and acquire technology (Dwoskin 2016).

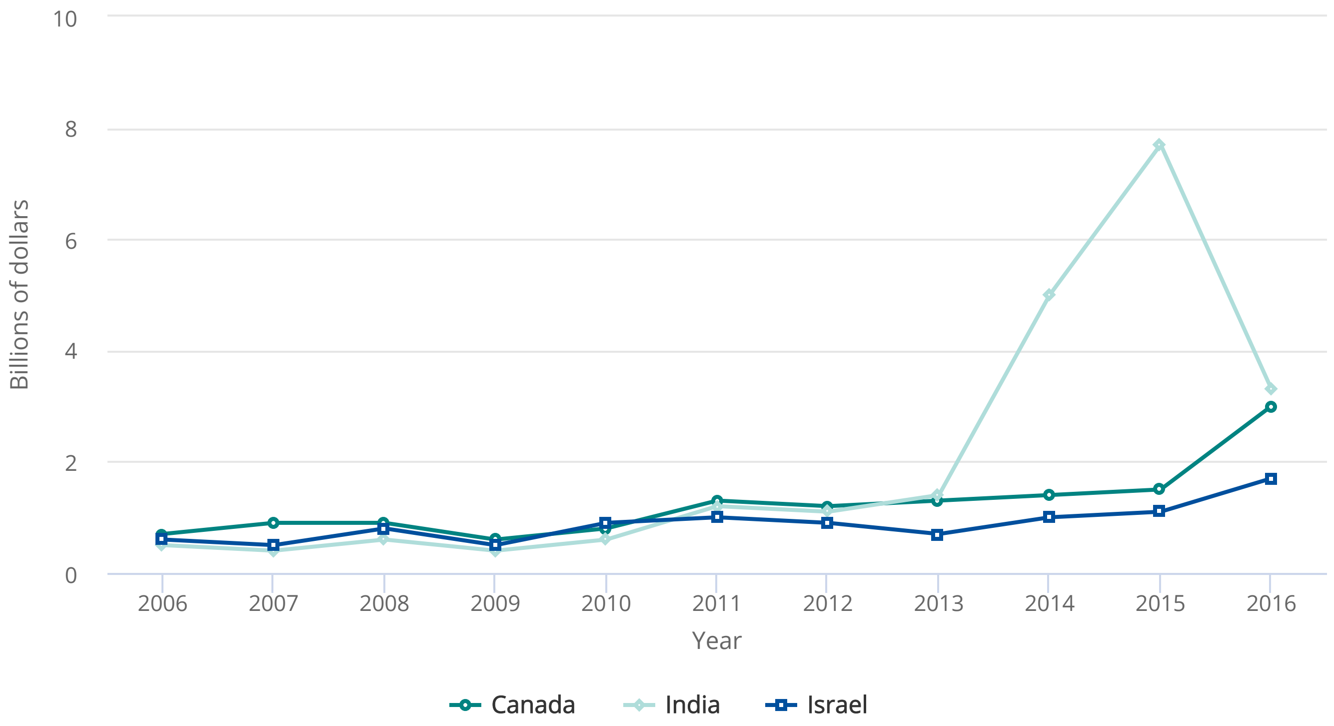
In other regions and economies, investment in the EU rose from $6 billion in 2013 to $11.0 billion in 2016 (Figure 8-22; Appendix Table 8-30). After spiking from $1.4 billion in 2013 to $7.7 billion in 2015, investment in India fell to $3.3 billion in

2016, more than double its level in 2013 (Figure 8-23). The spike in venture capital funding has been due to several factors, including the election of the first single-party government in 30 years, strong macroeconomic fundamentals, India's focus on S&T in higher education, and the country's strong position and expertise in business services and e-commerce.[1]

Investment in Israel more than doubled from $0.7 billion in 2013 to $1.7 billion in 2016 (Figure 8-23; Appendix Table 8-30). The expansion of venture capital outside of the United States, particularly in China, coincides with the globalization of finance, greater commercial opportunities in rapidly growing developing countries, and the decline of yields on existing venture capital investments in U.S.-based companies.[2]

FIGURE 8-23

Early- and later-stage venture capital investment, by selected country: 2006–16



Note(s)

Early-stage financing supports product development and marketing, the initiation of commercial manufacturing, and sales; it also supports company expansion and provides financing to prepare for an initial public offering. Later-stage financing includes acquisition financing and management and leveraged buyouts.

Source(s)

PitchBook, venture capital and private equity database https://my.pitchbook.com/.

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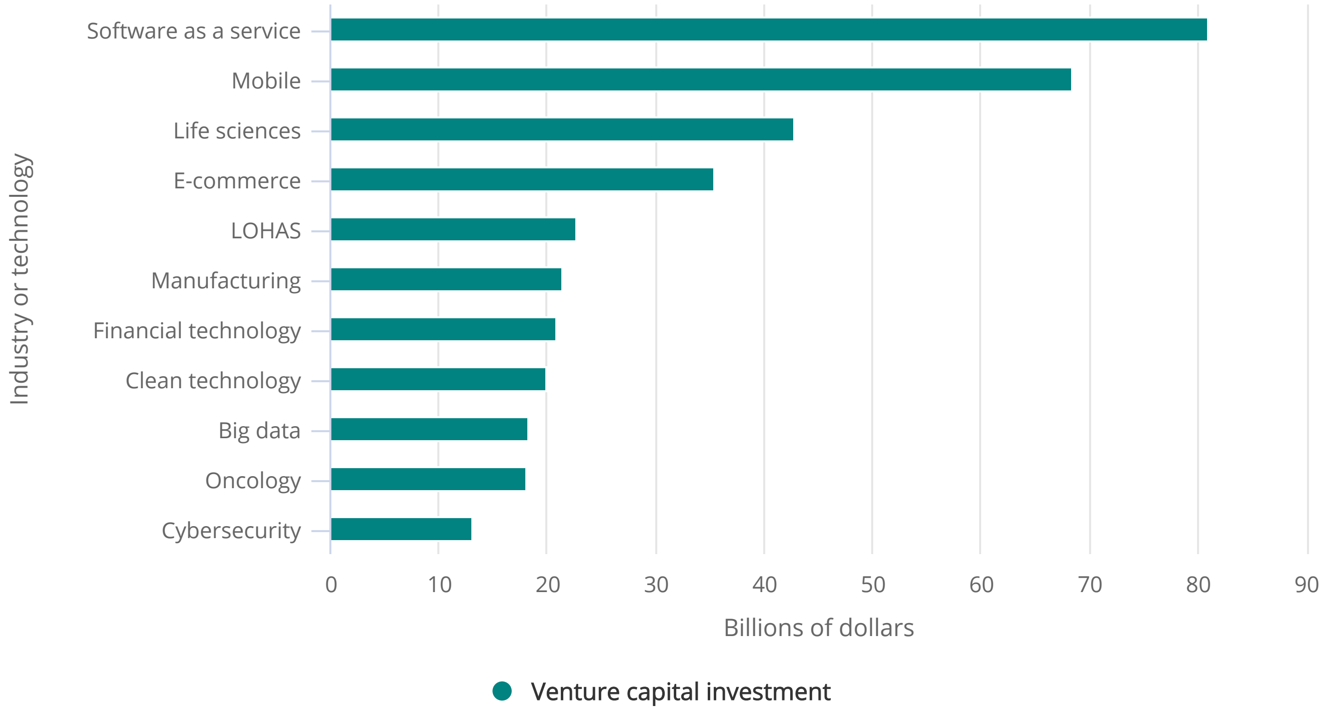
U.S. early- and later-stage venture capital investment by industry

Between 2011 and 2016, software as a service ($81 billion) and mobile ($68 billion) received the largest total amount of early- and later-stage venture capital investment (Figure 8-24; Appendix Table 8-33). These two industries also received the largest amounts of seed-stage investment during this period. The next two largest were life sciences ($43 billion) and e-commerce ($35 billion)—the former being a technology that is closely tied to basic science. Four industries—lifestyles of health and sustainability, manufacturing, financial technology, and clean technology—each received $20 billion to $23 billion. Big data received comparatively less early- and later-stage investment ($18 billion), although it ranked high in seed-stage investment (Figure 8-19).

FIGURE 8-24

U.S. early- and later-stage venture capital investment, by selected industry: 2011–16



LOHAS = lifestyles of health and sustainability.

Note(s)

Early-stage financing supports product development and marketing, the initiation of commercial manufacturing and sales; it also supports company expansion and provides financing to prepare for an initial public offering. Later-stage financing includes acquisition financing and management and leveraged buyouts. Industries ranked by the sum of investment between 2011 and 2016. Venture capital investments in firms are classified into industry verticals. The sum of investment in industry verticals exceeds total investment because firms that have activities in multiple industries or technologies are classified in multiple industry verticals.

Source(s)

PitchBook, venture capital and private equity database, https://my.pitchbook.com/.

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Rapidly growing early- and later-stage investment in industries may be an indication that these areas are maturing and moving from radical or transformative to more incremental technological change. Between 2013 and 2016, ephemeral content, technologies that provide online sharing and temporary display of photographs and other content, had the most rapid growth in investment (193% annualized average) among all industries, soaring from $74 million to $1.9 billion (Figure 8-21; Appendix Table 8-33). More than 20 companies, including Snapchat, Instagram, and Periscope, have received venture capital financing for this rapidly growing sector.[3] Venture capital and other investors sold Snapchat to the public in a IPO in March 2017 (Balakrishnan 2017).[4]

Investment in virtual reality grew the second fastest (104% annualized average rate), rising from $164 million to $1.4 billion (Figure 8-21; Appendix Table 8-33). Autonomous cars had the third fastest increase (102% annualized average), jumping from $56 million to $459 million. More than 70 companies, including Tesla, Mobileye, and Delphi Automotive, have received venture capital financing in this sector to develop software, computers, cameras, radar sensors, and other technologies.[5] Most major automakers are conducting pilot tests of autonomous cars or have made large investments in or acquisitions of companies with autonomous driving technologies (Gates et al. 2016).

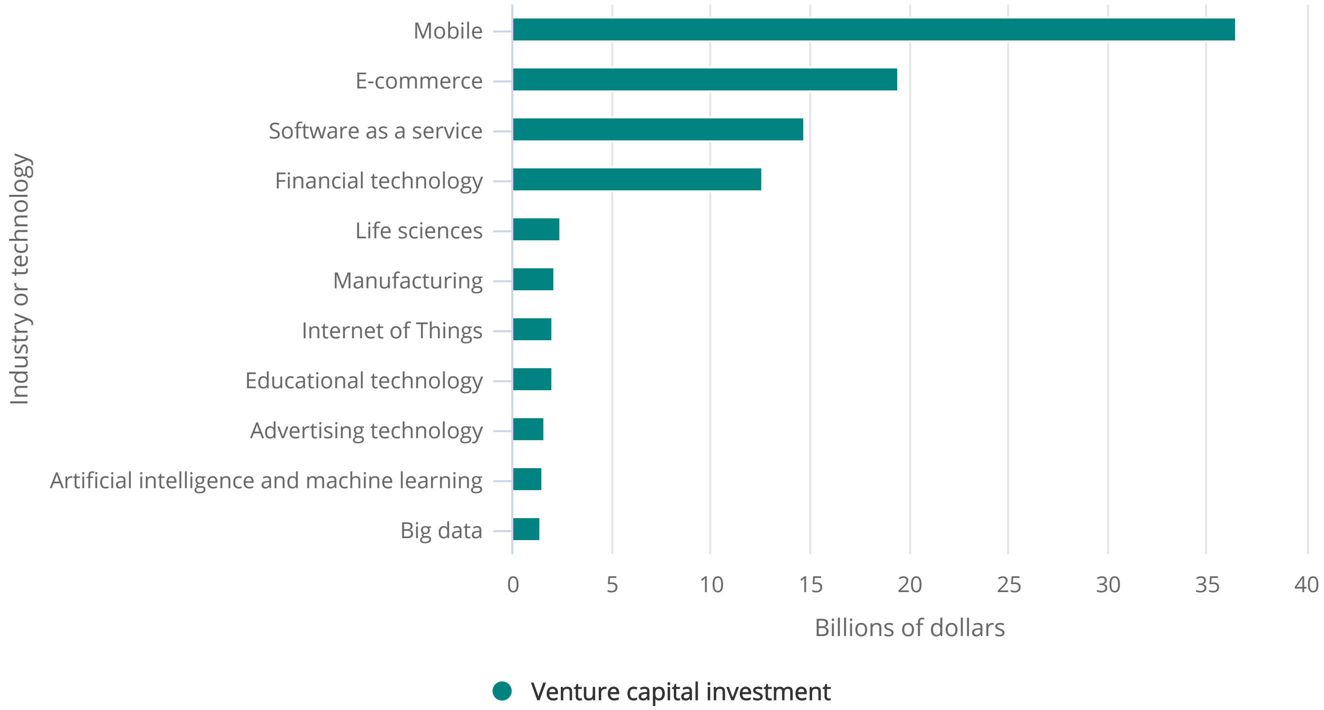
Investment in three-dimensional printing increased from $86 million to $612 million (92% annualized average). Lifestyles of health and sustainability grew the sixth fastest (79% annualized average rate), from $1.5 billion to $8.7 billion in 2016. (Lifestyles of health and sustainability consists of companies that provide consumer products or services focused on health, the environment, green technology, social justice, personal development, and sustainable living.) Early- and later-stage investment in artificial intelligence and machine learning, which has rapidly growing seed-stage investment, rose from $1.2 billion in 2013 to $3.9 billion in 2016.

Early- and later-stage venture capital investment in China by industry

Between 2011 and 2016, mobile technology was the leading industry receiving early- and later-stage investment ($37 billion) in China (Figure 8-25; Appendix Table 8-34). This industry received the second largest investment in the United States (Figure 8-24). E-commerce was the second largest ($19) in China and the fourth largest in the United States. Software as a service was the third largest, receiving $15 billion; this industry received the most investment in the United States. Life sciences, a technology that is closely tied to basic science, was the fifth largest, receiving comparatively little investment ($2 billion) compared with the four leading industries. This industry was the third largest in the United States, receiving far more investment ($43 billion) than in China.

FIGURE 8-25

China early- and later-stage venture capital investment, by selected industry: 2011–16



LOHAS = lifestyles of health and sustainability.

Note(s)

Early-stage financing supports product development and marketing, the initiation of commercial manufacturing, and sales; it also supports company expansion and provides financing to prepare for an initial public offering. Later-stage financing includes acquisition financing and management and leveraged buyouts. Amount of investment is the sum between 2011 and 2016. Venture capital investments in firms are classified into industry verticals. The sum of investment in industry verticals exceeds total investment because firms that have activities in multiple industries or technologies are classified in multiple industry verticals.

Source(s)

PitchBook, venture capital and private equity database, https://my.pitchbook.com/.

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Government Policies and Programs to Reduce Barriers to Innovation

Starting in the late 1970s, concerns by national policymakers about the comparative strength of U.S. industries and their ability to succeed in the increasingly competitive global economy took on greater intensity. The issues raised included whether the new knowledge and technologies flowing from federally funded R&D were being effectively exploited for the benefit of the national economy, whether pervasive barriers existed in the private marketplace that worked to slow businesses in exploiting new technologies for commercial applications and implementing innovations, and whether better public-private partnerships for R&D and business innovation had the potential to enhance the nation's economy to respond to these emerging challenges (Tassey 2007). There was also a concern about how to avoid inappropriately placing the government in positions to substitute for private business decisions better left to the competitive marketplace.

Many national policies and related programs have been directed at these challenges over the last 30 years. One major national policy thrust has been to enhance formal mechanisms for transferring knowledge arising from federally funded and performed R&D (Crow and Bozeman 1998; National Research Council [NRC] 2003), a topic discussed in the chapter's previous section. Another important development has been clearer recognition by policymakers, entrepreneurs, and the investment capital sector that structural and market barriers—often termed technological and commercial "valleys of death"—can arise in the marketplace that create difficult-to-bridge gaps for the innovation process and all too many barrier-filled pathways for otherwise promising new technologies (Branscomb and Auerswald 2002; Jenkins and Mansur 2011). These insights and an associated set of diagnostic concepts have given rise to several government programs intended to address the main sources for the gaps, with the intent of strengthening the prospects for the development and flow of early-stage technologies into the commercial marketplace. Other policy initiatives have included a particular focus on accelerating the commercial exploitation of academic R&D and encouraging the conduct of R&D on ideas and technologies with commercial potential by entrepreneurial small and/or minority-owned businesses.

The sections immediately following focus on this second theme of the commercial exploitation of federally funded R&D and review status indicators for several significant federal policies and programs directed at these objectives.

Small Business Innovation–Related Programs

The Small Business Innovation Research (SBIR) program and Small Business Technology Transfer (STTR) program are longstanding federal programs that provide competitively awarded funding to small businesses for purposes including stimulating technological innovation, addressing federal R&D needs, increasing private-sector commercialization of innovations flowing from federal R&D, and fostering technology transfer through cooperative R&D between small businesses and research institutions. The U.S. Small Business Administration (SBA) provides overall coordination for both programs, with implementation by the federal agencies that participate (SBA 2015).

The SBIR program was established by the Small Business Innovation Development Act of 1982 (P.L. 97–219) to stimulate technological innovation by increasing the participation of small companies in federal R&D projects, increasing private-sector commercialization of innovation derived from federal R&D, and fostering participation by minority and disadvantaged people in technological innovation. The program has received several extensions from Congress since then and is presently authorized through 2017. Eleven federal agencies participate in the SBIR program: USDA, DOC, DOD, the Department of Education, DOE, HHS, DHS, the Department of Transportation, the Environmental Protection Agency, NASA, and NSF.

The STTR program was established by the Small Business Technology Transfer Act of 1992 (P.L. 102–564, Title II) to facilitate cooperative R&D by small businesses, universities, and nonprofit research organizations and to encourage the transfer of technology developed through such research by entrepreneurial small businesses. Congress has likewise provided several extensions since it was initially enacted, with the program continuing through 2017. Five federal agencies participate in the STTR program: DOD, DOE, HHS, NASA, and NSF.

For SBIR, federal agencies with extramural R&D budgets exceeding $100 million annually must currently (FY 2017) set aside at least 3.2% for awards to U.S.-based small businesses (defined as those with fewer than 500 employees, including any affiliates). (The set-aside minimum was 2.5% for FYs 1997–2011, rising incrementally to 2.9% in FY 2015, 3.0% in FY 2016, and 3.2% in FY 2017.) Three phases of activities are recognized. In Phase I, a small company can apply for a Phase I funding award (normally not exceeding $150,000) for up to 6 months to assess the scientific and technical feasibility of an idea with commercial potential. Based on the scientific and technical achievements in Phase I and the continued expectation of commercial potential, the company can apply for Phase II funding (normally not exceeding $1 million) for 2 years of further development. Where the Phase I and II results warrant, the company pursues a course toward Phase III commercialization. The SBIR program itself does not provide funding for Phase III; depending on the agency, however, Phase III may involve non-SBIR-funded R&D or production contracts for products, processes, or services intended for federal government use. Several agencies offer bridge funding to Phase III and other commercialization support for startups (NRC 2008:208–16).

The initial round of SBIR awards was for FY 1983. This yielded 789 Phase I awards, across the participating agencies, for a total of $38.1 million of funding (▦ Table 8-7; Appendix Table 8-35 and Appendix Table 8-36). The scale of the program expanded considerably thereafter. To date, the number of awards peaked in FY 2003, when the annual total of awards was 6,844 (5,100 Phase I awards and 1,744 Phase II awards). The peak in funding to date was FY 2010, with total funding of $2.300 billion ($565 million for Phase I awards and $1.735 billion for Phase II awards). More recently, however, the annual number of awards and funding totals have dropped somewhat (▦ Table 8-7). In FY 2015, the award total was 4,508 (2,939 Phase I awards and 1,569 Phase II awards), with total funding of $1.923 billion ($462 million for Phase I awards and $1.461 billion for Phase II awards). In FY 2015, most funding reflected awards by DOD (49%) and HHS (22%) (Appendix Table 8-36). DOE (10%), NASA (8%), and NSF (7%) accounted for smaller shares. The other six participating agencies were 1% or less of the total.

TABLE 8-7

SBIR and STTR awards funding, by type of award: Selected years, FYs 1983–2015

(Number of awards and funding in millions of dollars)

Fiscal year	Number of awards			Funding ($millions)		
	Total	Phase I	Phase II	Total	Phase I	Phase II
SBIR						
1983	789	789	0	38.1	38.1	0.0
1985	1,838	1,483	355	195.3	74.5	120.8
1990	3,220	2,374	846	453.3	120.9	332.4
1995	4,367	3,092	1,275	962.2	236.5	725.8
2000	5,286	3,941	1,345	1,058.9	293.7	765.1
2005	6,085	4,216	1,869	1,862.5	452.5	1,410.0
2010	6,258	4,301	1,957	2,300.1	564.9	1,735.2
2011	5,403	3,628	1,775	2,052.4	507.6	1,544.8
2012	5,015	3,417	1,598	2,037.8	561.7	1,476.1
2013	4,520	3,017	1,503	1,927.0	489.9	1,437.1
2014	4,598	3,092	1,506	1,983.8	502.6	1,481.2
2015	4,508	2,939	1,569	1,922.8	462.0	1,460.8
STTR						
1983	na	na	na	na	na	na
1985	na	na	na	na	na	na
1990	na	na	na	na	na	na
1995	1	1	0	0.1	0.1	0.0
2000	410	315	95	64.0	23.7	40.3
2005	801	579	222	226.4	66.1	160.3
2010	903	625	278	298.7	78.9	219.8
2011	709	468	241	266.6	67.7	198.9
2012	637	467	170	222.5	73.1	149.4
2013	642	456	186	218.9	74.1	144.7

Fiscal year	Number of awards			Funding ($millions)		
	Total	Phase I	Phase II	Total	Phase I	Phase II
2014	703	493	210	284.2	95.1	189.1
2015	725	553	172	257.6	98.5	159.1

na = not applicable.

SBIR = Small Business Innovation Research; STTR = Small Business Technology Transfer.

Note(s)

The first SBIR program awards were made in FY 1983. The first STTR program award was made in FY 1995. Detail may not add to total due to rounding.

Source(s)

U.S. Small Business Administration, SBIR/STTR official website, https://www.sbir.gov/awards/annual-reports, accessed 1 March 2017. See Appendix Table 4-31 through Appendix Table 4-33.

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For the STTR program, federal agencies with extramural R&D budgets that exceed $1 billion annually must currently (FY 2017) reserve not less than 0.45% for STTR awards to small businesses. (The set-aside minimum was 0.3% for FYs 2004–11, rising incrementally to 0.4% in FYs 2014–15 and to 0.45% in FY 2016 and thereafter.) STTR operates within the same three-phase framework as SBIR. Phase I provides awards for company efforts to establish the technical merit, feasibility, and commercial potential of proposed projects; the funding in this phase normally does not exceed $100,000 over 1 year. Phase II is for continued R&D efforts, but award depends on success in Phase I and continued expectation of commercial potential. Phase II funding normally does not exceed $750,000 over 2 years. Phase III is for the small business to pursue commercialization objectives, based on the Phase I and II results. The STTR program does not provide funding for Phase III activities. Furthermore, to pursue Phase III, companies must secure non-STTR R&D funding and/or production contracts for products, processes, or services for use by the federal government.

The STTR program started with a single Phase I award for $100,000 in FY 1995 (▦ Table 8-7; Appendix Table 8-35 and Appendix Table 8-37). This program has also expanded considerably in subsequent years. The peak years to date for number of awards were FY 2004, with a total of 903 awards (719 Phase I awards and 184 Phase II awards), and FY 2010, also with 903 awards (625 Phase I awards and 278 Phase II awards). The peak in total funding was $299 million in FY 2010 ($79 million for Phase I and $220 million for Phase II). In FY 2015, 725 awards were made (553 for Phase I and 172 for Phase II), with funding totaling $258 million ($99 million for Phase I and $159 million for Phase II). Fewer federal agencies participate in STTR, but those dominant in SBIR are also dominant in STTR. STTR awards from DOD accounted for 49% of the $258 million award total in FY 2015 (Appendix Table 8-37). HHS accounted for 24% of the STTR awards, and the remaining awards were from DOE (10%), NASA (9%), and NSF (8%).

Other Federal Programs

The federal policies, authorities, and incentives established by the Stevenson-Wydler Technology and Innovation Act (and the subsequent amending legislation) and the SBIR and STTR programs are far from the whole of federal efforts to promote the transfer and commercialization of federal R&D. Many programs for these purposes exist in the federal agencies. These programs typically have objectives that closely reflect the specifics of agency missions and draw resources at levels well below the federal-wide SBIR and STTR programs. Several of the larger programs currently run by federal R&D performing agencies are briefly described in Table 8-8. A larger group of such federal agency policies and programs is documented in Appendix Table 8-38. Following Table 8-8, commentary is offered on three particularly well-known programs: DOC's Hollings Manufacturing Extension Partnership, DOE's Advanced Research Projects Agency-Energy, and NSF's Industry/University Cooperative Research Centers.

TABLE 8-8

Examples of federal policies and programs supporting early-stage technology development and innovation

(Summary of program goals and activities for selected federal agencies)

Agency, office, and program
Department of Agriculture
Under Secretary for Research, Education, and Economics
Agricultural Research Service (ARS)
Program name: Agricultural Research Partnerships (ARP) Network
Program goals: The ARS founded the ARP Network to expand the impact of ARS research and provide resources to help ARS commercial partners grow.
Program activities: The ARP Network matches business needs with ARS innovations and research capabilities and provides business assistance services to help companies and startups solve agricultural problems, develop products, and create new jobs. The ARP Network assists ARS in creating new partnerships and in supporting existing partnerships to advance ARS R&D efforts and subsequent utilization, including commercialization. Some of the ARP Network activities include matching industry needs with ARS patents and researchers for partnering; providing access to ARS research expertise, facilities, and equipment; and assisting in identifying sources of funding. The ARP Network is composed of organizations interested in agriculture-based economic development.
Department of Defense
Department Wide
Program name: Manufacturing Technology (ManTech) Program
Program goals: The Defense-Wide Manufacturing Science & Technology (DMS&T) ManTech Program was established to address cross-cutting, game-changing initiatives that are beyond the scope of any one Military Department or Defense Agency.
Program activities: ManTech seeks to address defense manufacturing needs, transition manufacturing R&D processes into production applications, attack manufacturing issues, and explore new opportunities.
Department of Health and Human Services

Agency, office, and program
National Institutes of Health (NIH)
National Center for Advancing Translational Sciences (NCATS)
Program name: Therapeutics for Rare and Neglected Diseases (TRND)
Program goals: The TRND program supports pre-clinical development of therapeutic candidates intended to treat rare or neglected disorders, with the goal of enabling an Investigational New Drug (IND) application to the Food and Drug Administration (FDA).
Program activities: The TRND program encourages and speeds the development of new treatments for diseases with high unmet medical needs. The program advances the entire field of therapeutic development by encouraging scientific and technological innovations to improve success rates in the crucial pre-clinical stage of development. TRND stimulates therapeutic development research collaborations among NIH and academic scientists, nonprofit organizations, and pharmaceutical and biotechnology companies working on rare and neglected illnesses. The program provides NIH's rare and neglected disease drug development capabilities, expertise, clinical resources, and regulatory expertise to research partners to optimize promising therapeutics and move them through pre-clinical testing, with the goal to generate sufficient-quality data to support successful IND applications and first-in-human studies in limited circumstances.
Department of Transportation
Federal Highway Administration (FHWA)
Office of Innovative Program Delivery
Program name: State Transportation Innovation Council (STIC) Incentive Program
Program goals: The STIC Incentive Program offers technical assistance and resources to support the standardization of innovative practices among state transportation agencies and other public sector stakeholders.
Program activities: The STIC Incentive Program provides up to $100,000 per State per Federal fiscal year to STICs to support or offset the costs of standardizing innovative practices in a State transportation agency (STA) or other public sector STIC stakeholder. STIC Incentive Program funding may be used to conduct internal assessments; build capacity; develop guidance, standards, and specifications; implement system process changes; organize peer exchanges; offset implementation costs; or conduct other activities the STIC identifies to address Technology and Innovation Deployment Program (TIDP) goals.
National Aeronautics and Space Administration
Human Exploration and Operations Mission Directorate

Agency, office, and program
Advanced Exploration Systems Division
Program name: Next Space Technologies for Exploration Partnerships (NextSTEP)
Program goals: The NextSTEP program is a public-private partnership model that encourages commercial development of deep space exploration capabilities to support more extensive human spaceflight missions in the Proving Ground around and beyond cislunar space—the space near Earth that extends just beyond the moon.
Program activities: NextSTEP stimulates the commercial space industry to help NASA achieve its strategic goals and objectives for expanding the frontiers of knowledge, capability, and opportunities in space. The NextSTEP partnership model provides an opportunity for NASA and industry to partner to develop capabilities that meet NASA human space exploration objectives while also supporting industry commercialization plans. Through these public-private partnerships, NextSTEP partners provide advance concept studies and technology development projects in the areas of advanced propulsion, habitation systems, and small satellites.
National Science Foundation
Directorate for Engineering
Division of Industrial Innovation and Partnerships (IIP)
Program name: Innovation Corps Program (I-Corps™; NSF, NIH, DoD, DoE, and USDA all have I-Corps programs)
Program goals: The I-Corps Program aims to foster entrepreneurship that will lead to the commercialization of technology that has been supported previously by NSF-funded research. The program provides entrepreneurial education for federally-funded scientists and engineers, pairing them with business mentors for an intensive curriculum focused on discovering a demand-driven path from their lab work to a marketable product.
Program activities: There are three distinct components of I-Corps: Teams, Nodes, and Sites. I-Corps Teams include NSF-funded researchers who will receive additional support—in the form of mentoring and funding—to accelerate innovation that can attract subsequent third-party funding. Nodes serve as hubs for education, infrastructure, and research that engage academic scientists and engineers in innovation; they also deliver the I-Corps Curriculum to I-Corps Teams. I-Corps Sites are academic institutions that catalyze the engagement of multiple, local teams in technology transition and strengthen local innovation.

Note(s)

The table summarizes examples of policy and program information collected during the spring and fall of 2017 from federal staff for a selected set of U.S. agencies with major R&D and technology development activities. The table reflects agency responses. For a fuller list of federal policies and programs see Appendix Table 8-38.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics; SRI International, special tabulations of federal program information (2017).

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Hollings Manufacturing Extension Partnership

The Hollings Manufacturing Extension Partnership (MEP) is a nationwide network of manufacturing extension centers located in all 50 states and Puerto Rico. MEP was created by the Omnibus Foreign Trade and Competitiveness Act of 1988 (P.L. 100–418) and is headed by DOC's NIST (DOC/NIST 2017). The MEP centers (which are nonprofit) exist as a partnership among the federal government, state and local governments, and the private sector. MEP provides technical expertise and other services to small and medium-sized U.S. manufacturers to improve their ability to develop new customers, expand into new markets, and create new products. The centers work directly with manufacturers to engage specific issues, including innovation and business strategies, product development and prototyping, lean and process improvements, workforce development, supply chain development, technology scouting, and transfer. The centers also serve to connect manufacturers with universities and research laboratories, trade associations, and other relevant public and private resources. The MEP annual report for FY 2015 (the most recent report presently available) describes the national network of MEP centers as operating with a total budget of about $300 million annually—$130 million from the federal government (with more than $110 million going directly to the centers), with the balance from state and local governments and the private sector (DOC/NIST 2015). The MEP report indicates that technical expertise and other services were provided during FY 2015 to 29,101 U.S. manufacturing companies and attributes impacts of $8 billion in increased or retained sales, 68,477 jobs created or retained, and $1.2 billion in cost savings for these businesses. (These services and impact metrics are comparable with the reports of recent previous years.)

Advanced Research Projects Agency–Energy

DOE's Advanced Research Projects Agency–Energy (ARPA-E) provides funding, technical assistance, and market development to advance high-potential, high-impact energy technologies that are too early-stage for private-sector investment (DOE 2017). The main interest is energy technology projects with the potential to radically improve U.S. economic security, national security, and environmental quality—in particular, short-term research that can have transformational impacts, not basic or incremental research. The America COMPETES Act of 2007 (P.L. 110–69) authorized ARPA-E, and it received $400 million of initial funding through the American Recovery and Reinvestment Act of 2009 (P.L. 111–5). Federal funding (appropriations) for ARPA-E was $180 million in FY 2011, $275 million in FY 2012, $251 million in FY 2013 (reduced by budget sequestration that year), and $280 million in FYs 2014 and 2015. ARPA-E's annual report for FY 2015 (most recent available) indicated 81 new project awards in FY 2015, with a total of 542 funded projects and $1.49 billion of funding since the program's inception (DOE 2015). The program identifies 31 focused and 2 open project areas, with topics including advanced batteries, transportation technologies, solar energy, energy storage technologies, advanced carbon capture technologies, electric power transmission, distribution and control, biofuels, and improved building energy efficiencies.

Industry/University Cooperative Research Centers

NSF's Industry/University Cooperative Research Centers (IUCRC) program supports industry-university partnerships to conduct industrially relevant fundamental research, collaborative education, and the transfer of university-developed ideas, research results, and technology to industry (NSF 2017). NSF supports IUCRC through partnership mechanisms where, per NSF, the federal funding is typically multiplied 10–15 times by supplementary funding from businesses and other nonfederal sources. The IUCRC program report for 2015–16 (NSF/IUCRC 2017) indicates 68 centers across the United States, with more than 1,000 nonacademic members: 85% are industrial firms, with the remainder consisting of state governments, national laboratories, and other federal agencies. NSF's IUCRC program funding for the centers was about $17.2 million that year, with other sources of support (including NSF funds other than the IUCRC program; member fees; funds from industry; and funds from other federal agencies, state government, and other nonfederal government), bringing the total of center funding that year to $109.3 million. Research is prioritized and executed in cooperation with each center's membership organizations.

Innovation Activities by U.S. Business

The data presented thus far on invention, knowledge transfer, and innovation provide insights into the sources of knowledge, inventions, and funding for innovation, as well as the efforts by government and academic institutions to facilitate technology transfer and the early-stage development of useful technologies. Yet none of these measures provide a clear indicator for the incidence of innovation in firms—the implementation of a new or significantly improved product or business process. Firm-level survey data collected in the United States, Europe, and parts of Latin America, Asia, the Pacific, and South Africa provide industry-level data on the incidence of innovations, as well as rich ancillary data on related activities in firms. See sidebar 💬 Concepts and Definitions for Business Innovation Survey Data for more information on the framework behind the U.S. survey data on innovation collected by the National Center for Science and Engineering Statistics BRDIS. This U.S. survey is also the source of the R&D expenditure data reported in Chapter 4.

SIDEBAR

Concepts and Definitions for Business Innovation Survey Data

The Oslo Manual of the Organisation for Economic Co-operation and Development (OECD) and Eurostat (2005) provides a definition for firm-level innovation activity that countries and economies have widely used to enhance comparability of international data. Survey data are guided by this framework including, notably, the Community Innovation Surveys (CIS) from the European Union (EU) Statistical Office and the Business R&D and Innovation Survey (BRDIS) from NSF's National Center for Science and Engineering Statistics. Following *The Oslo Manual*, innovation is defined in these surveys as "implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method" (OECD/Eurostat 2005:46–47).

The CIS is a coordinated effort at comparable innovation data across EU countries, conducted in 28 EU states, and used as the basis for other countries' data collection. For the EU states, data collection is coordinated and integrated by the European Commission. The OECD also uses these data in its international comparisons for the Science, Technology, and Industry Scoreboard (http://www.oecd.org/innovation/inno/inno-stats.htm#indicators).

BRDIS, described in Chapter 4 as the source of U.S. business R&D expenditures, includes innovation questions derived from *The Oslo Manual* and the CIS. However, the U.S. survey data identify only new or significantly improved products and processes. Examination has shown that organizational innovation, marketing innovation, and other process innovations are often not distinct enough to be divisible for respondent reporting, a finding supported empirically by cognitive interview data (Tuttle et al. 2013). Innovation data on this survey have been collected for nonfarm U.S. private industries with five employees or more since 2008.

Per NSF's BRDIS, 17% of U.S. firms (or companies) reported introducing a new or significantly improved product or process during 2013–15 (▦ Table 8-9): 1 in 6 firms. This incidence rate of innovation varies across firm size and industry. Reported innovation rates increase overall with firm size. However, across all firms, more than 230,000 that have fewer than 250 employees (and at least 5) had introduced a product or process innovation. For large firms, those with 250 or more employees, more than 6,500 introduced innovations.

TABLE 8-9

U.S. companies introducing new or significantly improved products or processes, by company size and industry sector: 2013–15

(Number and percent)

Company size and industry	Companies (number)[a]	Percent reporting product and/or process improvements
All companies (number of domestic employees)	1,413,932	16.8
Micro-companies		
5–9	550,695	13.4
Small companies		
10–19	422,056	17.8
20–49	287,091	18.7
Medium companies		
50–99	82,729	22.4
100–249	46,480	20.9
Large companies		
250–499	13,024	24.2
500–999	5,535	17.9
1,000–4,999	4,918	35.8
5,000–9,999	541	29.5
10,000–24,999	363	33.8
25,000 or more	500	68.9
All companies with 5 or more domestic employees		
Manufacturing industries (NAICS 31–33)	112,782	33.1
Nonmanufacturing industries (NAICS 21–23, 42–81)	1,301,150	15.4

NAICS = North American Industry Classification System.

[a] Statistics for the number of companies are based only on companies in the United States that reported data for at least one of the items on the survey relating to new or significantly improved products or processes, regardless of whether the company performed or funded R&D. These statistics do not include an adjustment to the weight to account for unit nonresponse.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, and U.S. Census Bureau, Business R&D and Innovation Survey (BRDIS), 2015.

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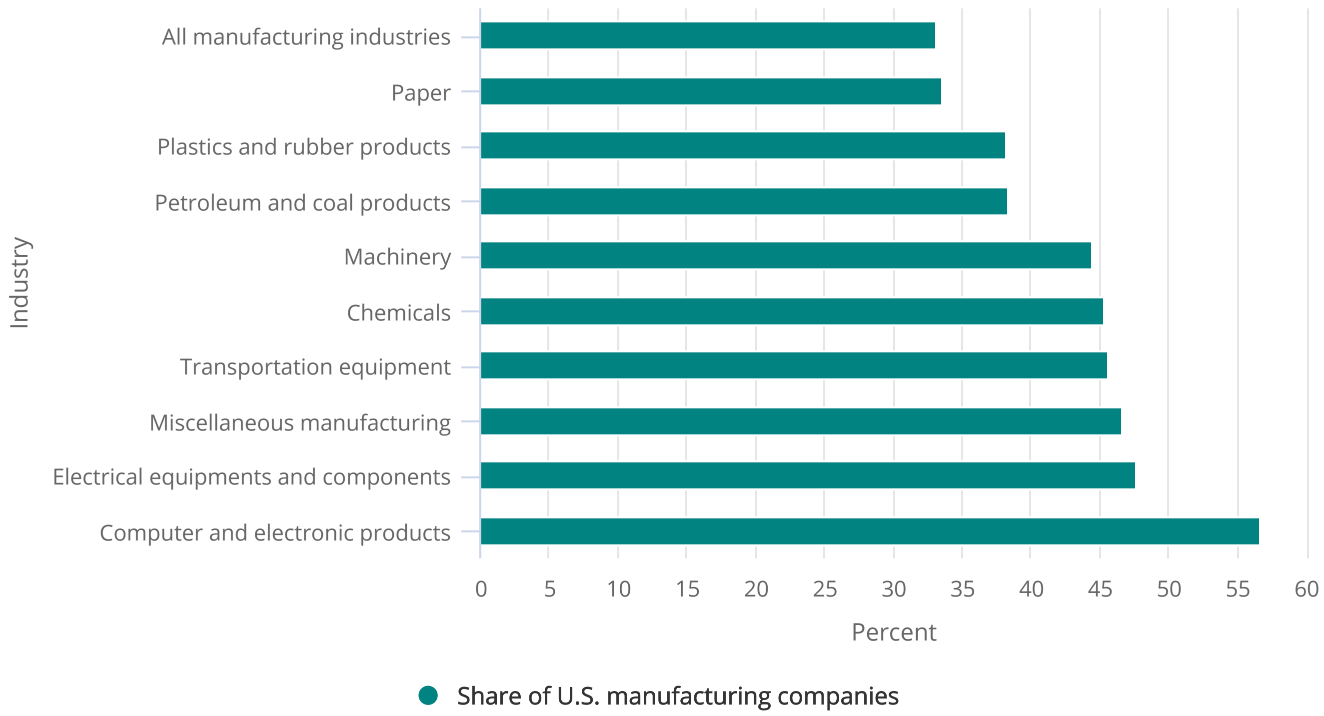
ICT-producing industries report many of the highest rates of innovation in manufacturing and in other sectors of the economy. Within manufacturing, almost half of electronic equipment and component firms, and more than half of computer and electronic products firms reported innovations between 2013 and 2015 (Figure 8-26). Outside of manufacturing firms, 44% of computer systems design firms and 31% of information industry firms reported innovations (Figure 8-27).

FIGURE 8-26

Share of U.S. manufacturing companies reporting product or process innovation, by selected industry: 2013–15



Note(s)

The survey asked companies to identify innovations introduced from 2013 to 2015. Electrical equipment includes appliances.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Business R&D and Innovation Survey (BRDIS) (2015)

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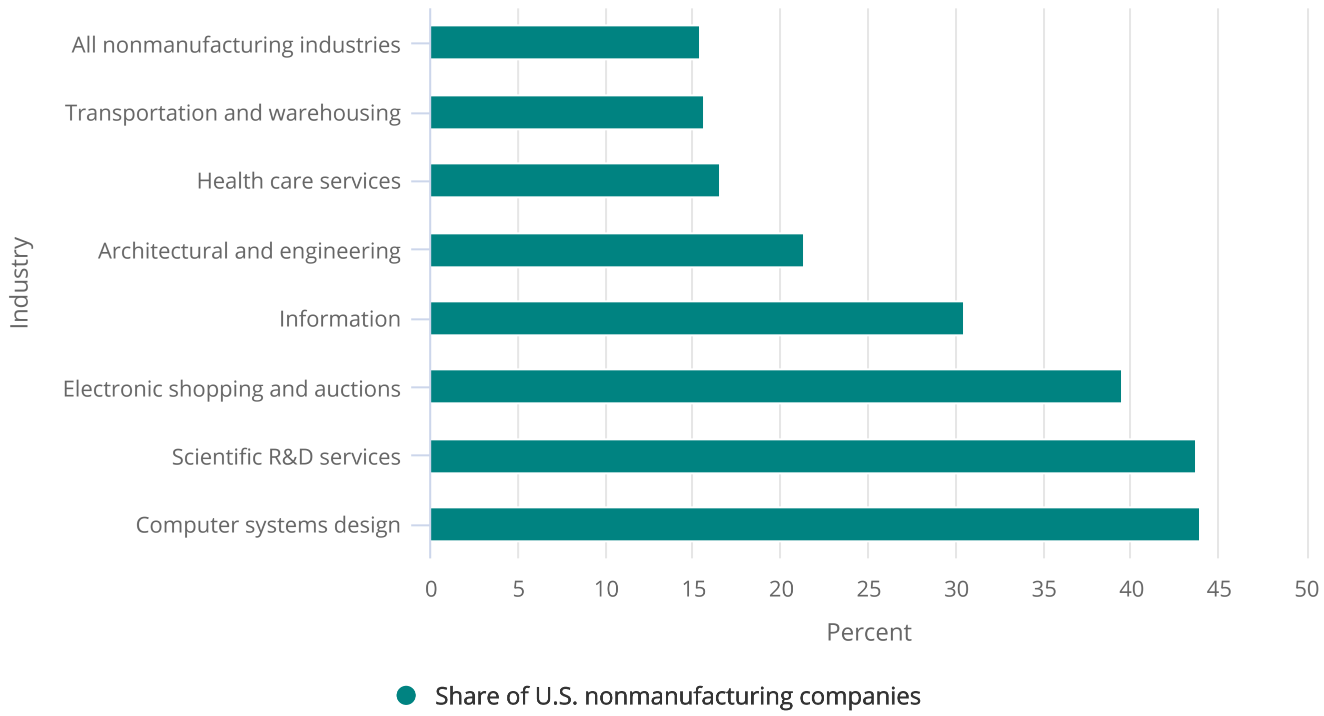
FIGURE 8-27

Share of U.S. nonmanufacturing companies reporting product or process innovation, by selected industry: 2013–15



Note(s)

The survey asked companies to identify innovations introduced from 2013 to 2015. Architectural and engineering category and Computer system design includes related services.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Business R&D and Innovation Survey (BRDIS) (2015), Table 68.

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Overall, one-third of manufacturing firms reported an innovation, accounting for more than 37,000 firms with innovations. Firms in paper (34%), plastics and rubber (38%), and petroleum and coal products (38%) report innovation rates above one third. For chemicals, transportation equipment, and miscellaneous manufacturing, the industry innovation incidence rates are higher yet—more than 40%.

Outside of manufacturing, 15% of firms, or 200,000 firms, reported innovations. In addition to the ICT-producing industries discussed earlier, transportation and warehousing, health care services, electronic shopping and auctions, and scientific R&D services, among others, have incidence rates above the nonmanufacturing average (Figure 8-27).

Focusing on product innovation compared with process innovation, manufacturing firms overall report product and process innovations at similar rates, about one-quarter of firms. For nonmanufacturing firms, these rates are about 1 in 10. Across industries, U.S. firms reported higher rates of process innovation compared to product innovation (▦Table 8-10).

TABLE 8-10

U.S. companies introducing new or significantly improved products or processes, by industry sector and industry proportions: 2013–15

(Number and percent)

Industry	NAICS code	New or significantly improved products or processes		New or significantly improved product (goods or services)				New or significantly improved processes				
		Companies (number)[a]	Percent	Companies (number)[a]	Any good or service	Goods	Services	Companies (number)[b]	Any processes	Manufacturing or production methods	Logistics, delivery, or distribution methods	Support activities
					Percent	Percent	Percent		Percent	Percent	Percent	Percent
All industries	21–23, 31–33, 42–81	1,413,932	16.8	1,406,937	10.4	6.4	7.7	1,396,470	12.4	5.1	4.3	9.7
Manufacturing industries	31–33	112,782	33.1	112,249	24.3	21.7	11.4	111,990	24.7	18.4	7.5	14.5
Nonmanufacturing industries	21–23, 42–81	1,301,150	15.4	1,294,688	9.2	5.0	7.4	1,284,480	11.3	4.0	4.1	9.3

[a] Statistics for the number of companies are based only on companies in the United States responding either "Yes" to at least one of the items on the survey relating to new or significantly improved products regardless of whether the company performed or funded R&D. These statistics do not include an adjustment to the weight to account for unit nonresponse.

[b] Statistics for the number of companies are based only on companies in the United States that reported data for at least one of the items on the survey relating to new or significantly improved products or processes, regardless of whether the company performed or funded R&D. These statistics do not include an adjustment to the weight to account for unit nonresponse.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, and U.S. Census Bureau, Business R&D and Innovation Survey (BRDIS), 2015, Table 68 and Table 69.

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International Comparisons in Innovation Incidence

Interest in international competitiveness drives cross-country comparisons of business innovation rates, and these indicators provide a uniquely focused measure of activity distinct from R&D.

The data described as follows are collected under *The Oslo Manual* (OECD/Eurostat 2005), discussed in the sidebar Concepts and Definitions for Business Innovation Survey Data. While differences in survey methodologies across countries continue to drive inconsistency among international data, broad patterns emerge. Across countries, the highest rates of product and process innovation are reported in relatively smaller, but S&T-focused economies, such as Switzerland, Israel, and Finland. In contrast, Japan, the United Kingdom (UK), and the United States all rank relatively low in reported incidence (Table 8-11).

Not surprisingly, country-level data show innovation incidence varies across firm size. Firms with 250 or more employees had higher innovation rates than smaller firms, with a notable exception. For Australia, small firms had a higher product innovation rate compared with larger firms.

TABLE 8-11

International comparison of innovation rate, product, and process, by country and firm size: 2012–14

(Percent of firms)

Country	Total	Fewer than 250 employees	250 employees or more
Product innovative firms (regardless of any other type of innovation)			
Switzerland	42.4	41.4	68.9
Israel	36.2	35.2	53.3
Ireland	35.7	34.3	66.1
Australia	35.7	35.8	31.1
Finland	34.5	33.2	64.6
Germany	34.4	33.0	62.8
Norway	32.9	32.3	48.4
Netherlands	32.5	31.8	49.8
Belgium	31.9	30.8	56.1
Sweden	31.4	30.4	58.3
Austria	30.8	28.9	69.0
Luxembourg	28.8	27.5	56.6
Portugal	28.4	27.5	64.3
France	27.7	26.2	59.0
United Kingdom	26.8	26.4	36.1
Slovenia	25.2	23.7	61.6
Czech Republic	25.1	23.4	55.9
Italy	24.7	24.0	58.3
Greece	23.4	22.8	65.6
Denmark	23.2	22.2	47.4
Turkey	22.7	22.1	36.5
Lithuania	20.9	19.9	54.5
China	18.7	NA	NA

Country	Total	Fewer than 250 employees	250 employees or more
Brazil	18.5	17.6	43.6
United States	18.4	NA	NA
New Zealand	18.1	17.8	38.1
South Korea	16.8	16.3	34.1
Japan	14.6	13.8	31.6
Slovak Republic	12.6	11.3	35.8
Hungary	12.0	11.1	32.1
Spain	11.2	10.3	43.9
Estonia	11.0	10.2	38.3
Poland	9.5	8.4	38.8
Latvia	8.5	7.7	35.4
Russian Federation	5.3	2.6	15.7
Chile	5.1	4.8	10.1
Process innovative firms (regardless of any other type of innovation)			
Belgium	38.8	37.8	62.9
Ireland	37.8	36.4	67.4
Portugal	35.4	34.6	67.8
Israel	34.0	31.9	71.1
Austria	32.8	30.9	70.1
Brazil	32.1	31.4	53.4
Finland	32.0	31.0	55.0
Lithuania	31.4	30.1	71.9
Australia	31.0	30.8	37.0
Greece	29.6	29.0	66.0
Netherlands	28.1	27.5	42.7
France	27.1	25.9	53.3
Norway	26.9	26.1	45.0

Country	Total	Fewer than 250 employees	250 employees or more
Turkey	26.8	26.2	42.9
Switzerland	26.1	25.0	53.9
Sweden	25.8	24.8	52.1
Luxembourg	25.7	24.7	44.6
Italy	24.5	23.8	58.3
Germany	24.1	22.3	60.5
Denmark	23.2	22.1	48.4
Slovenia	22.6	NA	NA
Czech Republic	22.4	20.5	56.3
China	20.0	NA	NA
United States	19.8	NA	NA
Japan	19.2	18.5	33.3
New Zealand	18.9	18.6	39.2
United Kingdom	17.9	17.6	25.9
South Korea	17.3	16.5	48.9
Spain	14.8	13.9	49.9
Estonia	13.0	12.1	43.9
Slovak Republic	12.9	11.7	34.8
Poland	10.9	9.7	42.6
Latvia	9.7	8.8	41.0
Hungary	9.6	8.7	30.2
Chile	8.2	7.5	18.8

NA = not available.

Note(s)

Where indicated, most recent data are used. Comparison is for North American Industry Classification System equivalents of International Standard Industrial Classification of All Economic Activities Revision 4 sectors and industries in the European Union Core Coverage: B (mining and quarrying); C (manufacturing); D and E (electricity, gas, steam, water supply, sewerage, waste management, remediation); G 46 (wholesale trade, except motor vehicles and motorcycles); H (transport and storage); J 58 (publishing); J 61 (telecommunications); J 62 (computer programming, consultancy, and related activities); J 63 (information services); K (finance and insurance); M 71 (architecture, engineering, technical testing and analysis).

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, and U.S. Census Bureau, Business R&D and Innovation Survey (BRDIS), 2015; Organisation for Economic Co-operation and Development (OECD), OECD Science, Technology and Industry Scoreboard 2015 (2015), https://www.oecd.org/sti/scoreboard.htm.

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Measurement and Data Challenges

Cross-national comparability complicate interpretation of the OECD innovation data. The subjective element in respondent identification of something “new or significantly improved” can vary systematically across countries, and may miss incremental improvements. Also, U.S. survey data identify only new or significantly improved products and processes, whereas Community Innovation Survey data include separate categories for organizational innovation and marketing innovation. Industry and firm size coverage also varies across countries for the surveys.

Statistical agencies have primarily focused their attention on business-sector activity. However, inventors and entrepreneurs have long played an important role in innovation. Individual innovators invent, implement, and share innovations, whether as a tool or as a hobby. Both kinds of activities generally fall outside the scope of business innovation surveys.[6]

Less well understood than business innovation, improvements in collaborative tools and Internet connectivity increase the importance of individual innovators (Gault and von Hippel 2009). Academic researchers in the United States, the UK, Japan, Finland, and South Korea gathered information on free innovation by households between 2012 and 2015, focusing on new product development and modifications (von Hippel 2017). Although relatively small scale (fewer than 2,000 respondents for the United States and the UK each), these surveys find household innovation rates between 1.5% for South Korea and 6.1% for the UK.[7]

Although this activity is less well understood than business innovation, improvements in collaborative tools and Internet connectivity increase this activity’s importance (Gault and von Hippel 2009). A design, computer program, or set of instructions, for example, can be shared for free through the Internet, allowing free reuse throughout the world. Teams of connected contributors add to potential impact.

Productivity Growth and Multifactor Productivity

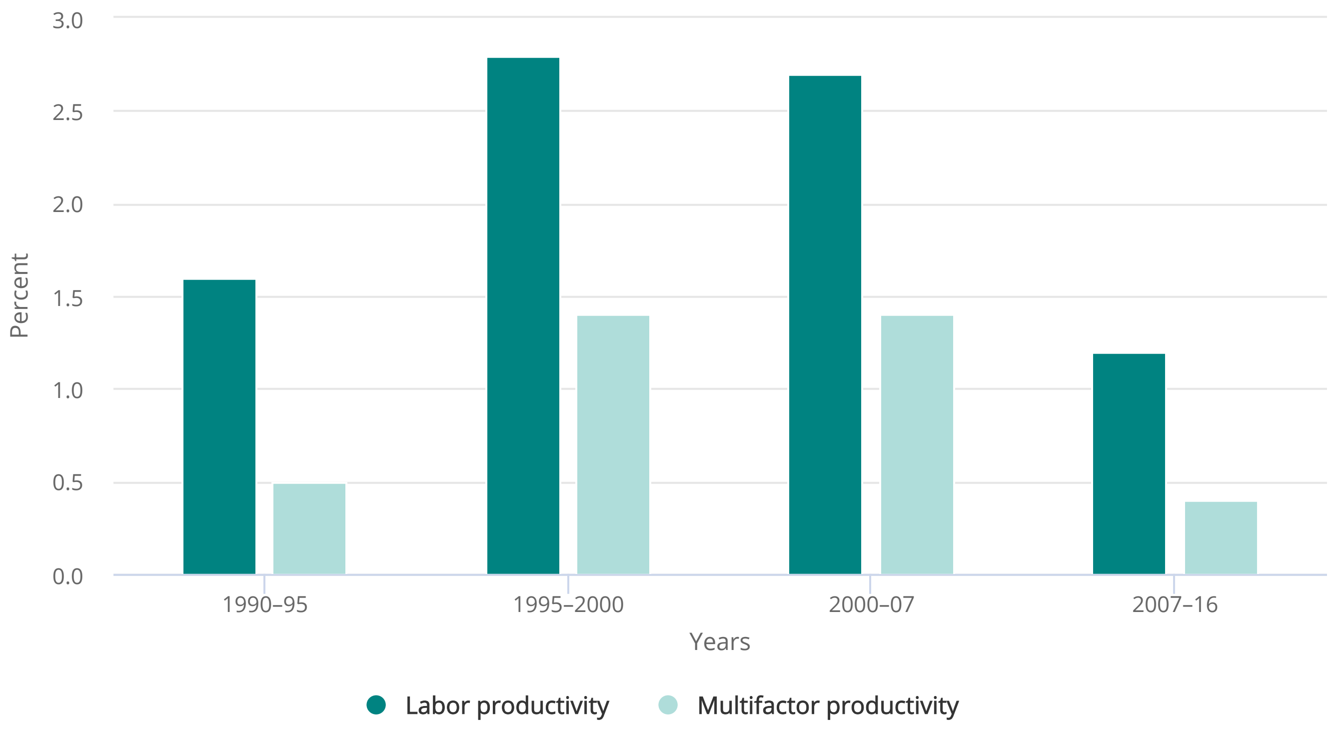
Innovations contribute to economic growth through cost savings from new and improved processes and from sales from new products. New knowledge about the innovation also spreads through the economy. New firms enter and competitive forces can shift the composition of output to higher-productivity firms. If this impact is sufficiently large, we might expect to see rising growth in the ratio of quantity of goods and services produced by workers (GDP) relative to hours worked, measured as labor productivity. Figure 8-28 shows U.S. labor productivity averages for four subperiods between 1990 and

2016. Overall, productivity growth in the United States has been on a declining trend since the early 2000s, including during the economic recovery after the Great Recession (Figure 8-28).

Many factors in addition to the impact of innovation contribute to productivity, including workforce skill and investments in physical and intangible capital. As an indicator of the impact of innovation on economic growth, productivity can be decomposed into component parts, where multifactor productivity is the part attributed to technology's overall impact on the economy. It is calculated as the output growth that cannot be attributed to labor and capital inputs, after accounting for changes in workforce skill and the quality of capital. Figure 8-28 shows that trends in MFP in the United States have been similar to trends in labor productivity: MFP grew faster on average between 1995 and 2007 compared with the first half of the 1990s, and growth moderated since 2007.

FIGURE 8-28

Labor and multifactor productivity annual growth, multiyear averages, private nonfarm business sector: 1990–2016



Note(s)

Growth is calculated by the Bureau of Labor Statistics (BLS) as the average annual rate of growth between the first year and the last year of each period.

Source(s)

BLS, Productivity Measures (2017), Private Non-Farm Business Sector (Excluding Government Enterprises), 30 March 2017 release, accessed 17 June 2017.

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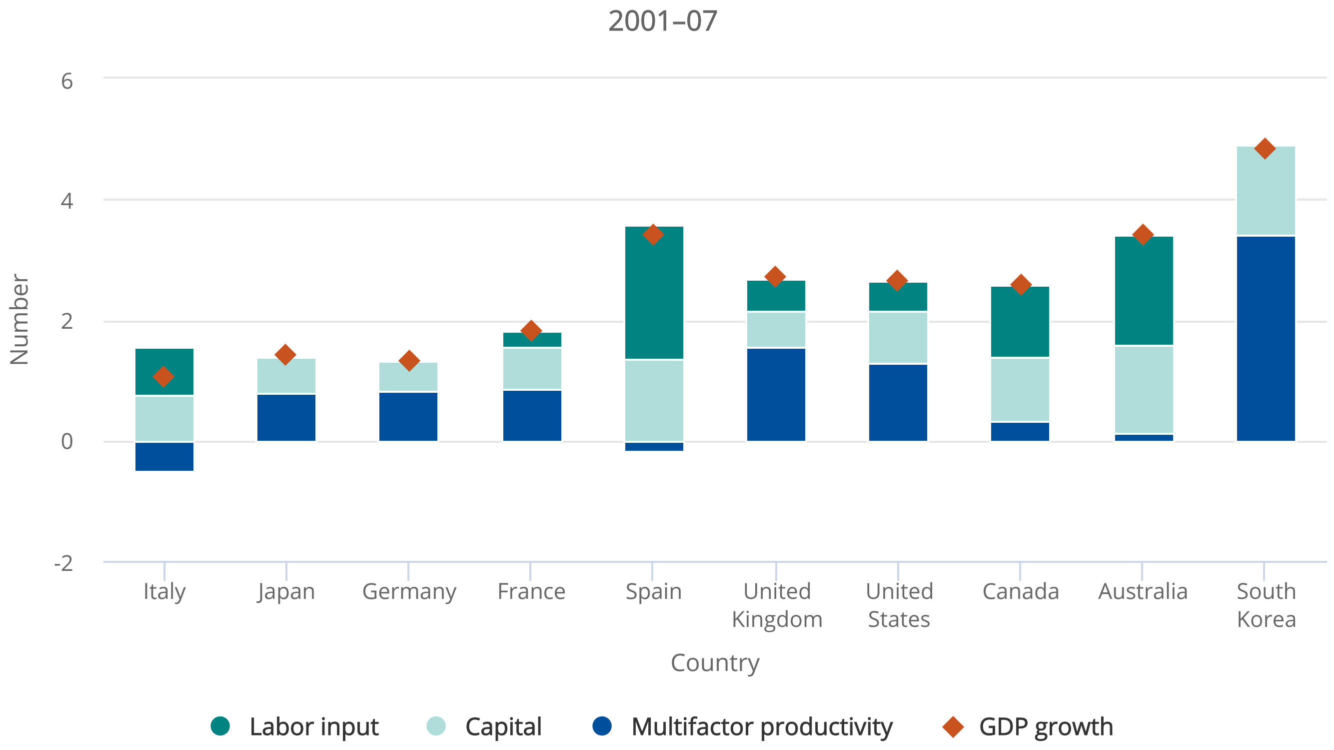
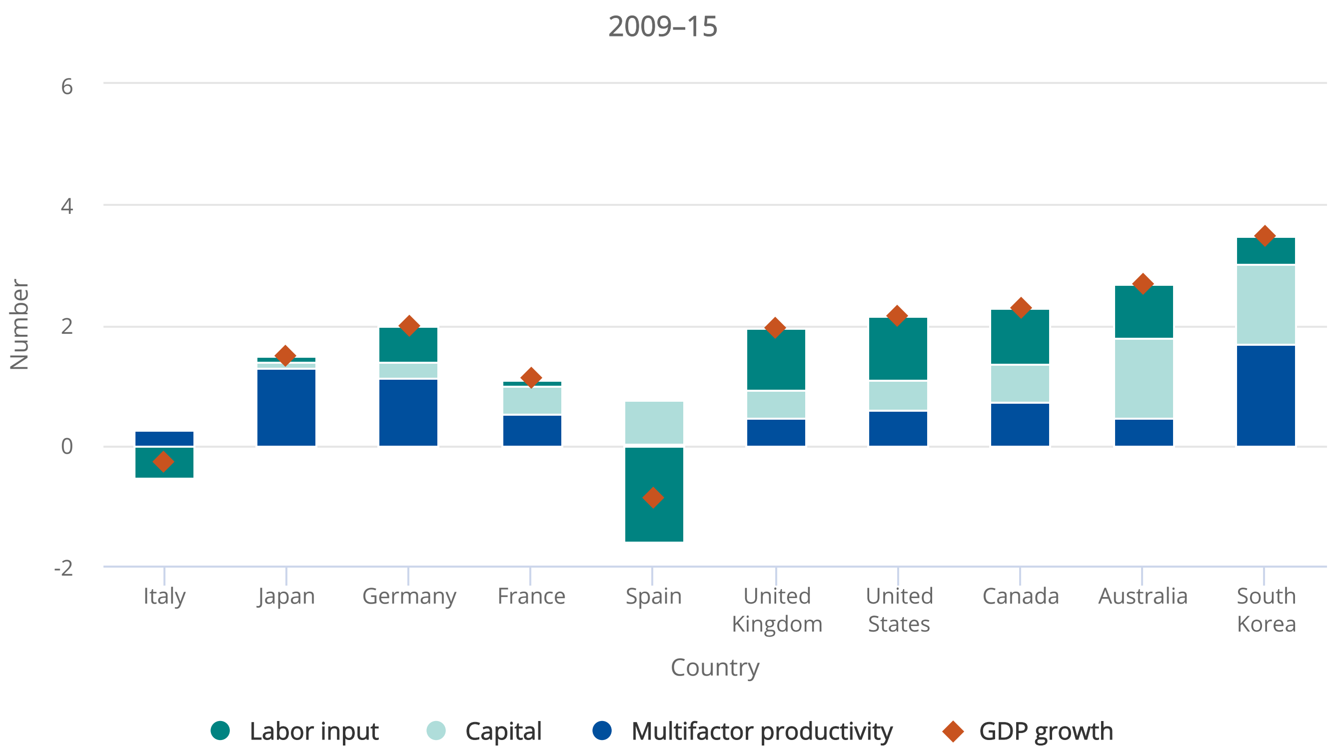
The moderation in the growth rate of MFP is evident in other developed economies as well, including France, Great Britain, and South Korea (OECD 2017). Figure 8-29 shows MFP and GDP growth for the 10 largest OECD countries for two periods: 2001 to 2007 and 2009 to 2015. For each country, the height of each bar is GDP growth. In addition to MFP, increases in labor and increases in capital used in the economy contribute to growth. The factors are shown in Figure 8-29 within each bar: labor input, capital input, and MFP. Only Germany had more than a nominal increase in overall productivity growth across these periods. For Germany, increases in labor and MFP contributed to the growth. For Japan, MFP contributions to growth offset smaller contributions from capital.

FIGURE 8-29

Contributions to GDP growth, average: 2001–07 and 2009–15, selected OECD countries





GDP = gross domestic product.

Note(s)

Data for Spain run through 2014.

Source(s)

Organisation for Economic Co-operation and Development (OECD), *OECD Compendium of Productivity Indicators 2017* (2017), http://dx.doi.org/10.1787/pdtvy-2017-en, Table 2.19, accessed 15 June 2017.

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More broadly, MFP growth has been depressed in both developed and developing economies since the global financial crisis of 2008. Lingering effects of the global recession may be responsible. Structural factors remaining from the recession include corporate debt ratios, misallocation of capital within and across sectors, slower ICT investment, and shifting preference toward less risky investments (Adler et al. 2017).

Many explanations for the slowdown focus on the pace of innovation and technology diffusion from ICT investment. Gordon (2016) argues that the period of the late 1990s to mid-2000s was one of unusually rapid growth from the spread of Internet-enabled communications, entertainment, and commerce, and that the future pace of innovation is unlikely to match this period. From this perspective, MFP is in a secular slowdown, with the gains from investment in ICT in the late 20th century having ended, and the major innovations of the late 19th and early 20th centuries were not and are unlikely to be followed by innovations that have as significant an effect on MFP growth.

An alternative explanation is that MFP growth may be delayed by lags between innovation and its systemic diffusion and adoption (Brynjolfsson and McAfee 2014). Historically, such delays have been especially prominent for general purpose technologies (GPTs; see sidebar 💬General Purpose Technologies), a special category of technologies that are widely used, capable of ongoing technical improvement, and enable innovation in application sectors (Bresnahan 2010).[8]

Measurement issues also effect the clarity of MFP as an indicator of the impact of innovation, since MFP is measured as a residual from economic data. High-quality expenditure data on inputs and outputs are necessary, and supplementary measures needed for good measurement are quantity, price, depreciation, and rate-of-return data for capital (Hall and Jaffe 2012).[9]

SIDEBAR

General Purpose Technologies

General Purpose Technologies (GPT) are a special category of technologies that are widely used, capable of ongoing technical improvement and of enabling innovation in application sectors (Bresnahan 2010). Historical examples are steam engines, the factory system, electricity, the chemical engineering discipline, semiconductors, digital technology, and the Internet. When these technologies become widespread, there are complementarities between technical improvement for the GPT and innovations in related application sectors that can lead to sustained economic growth (David 1990).

GPTs highlight the role of network effects, where the value of an input increases with additional users on the network. The U.S. railroad system complemented the invention of the steam engine and networks of roads complemented that invention of the automobile (Gordon 2016). Complementary innovations rise more easily in a standardized network, leading to an important role for standard setting.

A lesson from the history of GPTs is that the diffusion of a new application can take a long time (e.g., from the invention of the steam engine to its influence on economic growth). Factors that influence the speed of diffusion include the skill of the workforce and the capital with which they work. Bresnahan (2010) observes that the combination of the GPTs and their applications is what produces growth.

Small Fast-Growing Firms in the United States

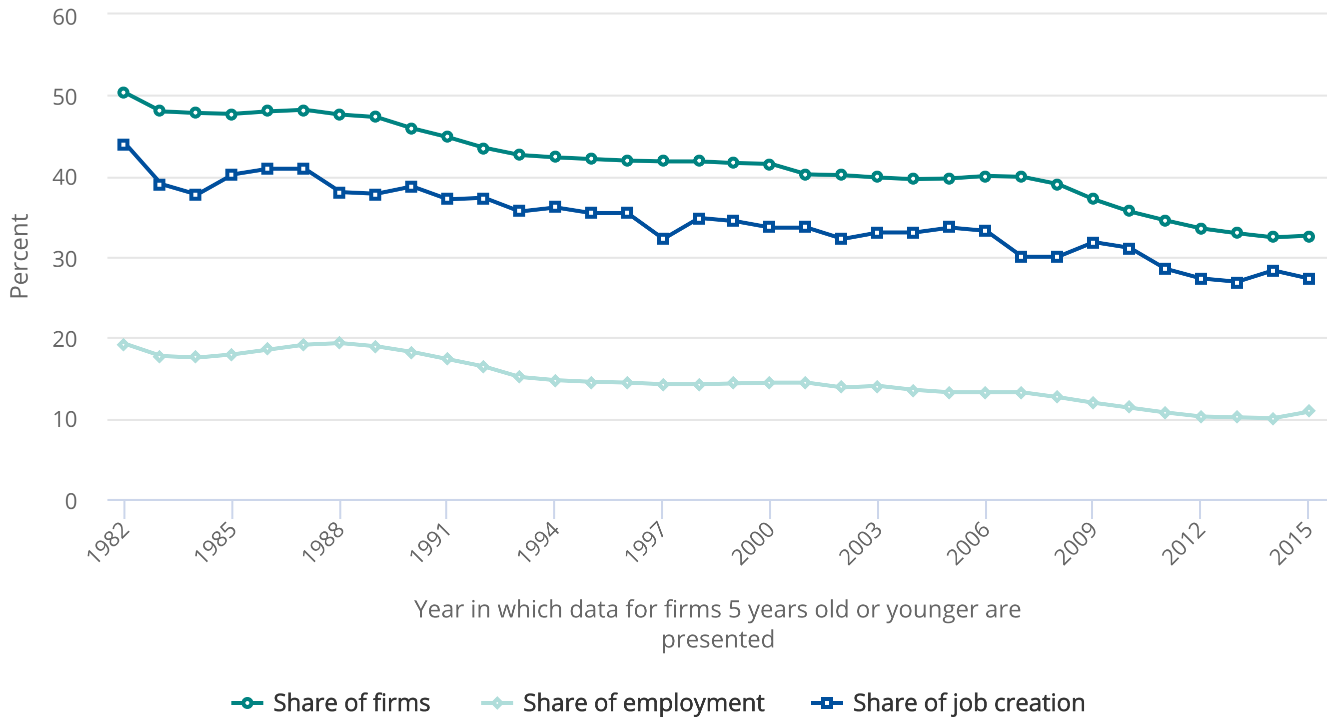
The policy implications for the apparent productivity slowdown are large, motivating better understanding of the causes of the slowdown at the level of individual firms. Changes in firms can be obscured by aggregate sector statistics. The data best suited to explore these dynamics are firm-level data (e.g., those available in the U.S. Census Bureau's Business Dynamics Statistics). These data provide information on establishments opening and closing, firm startups and shutdowns, and their associated employment impacts. The data show that business dynamism, as measured by new startup formation, has been declining in the last decade, leading to fewer firms and older firms (Decker et al. 2014). Importantly, since 2000, the number of high-growth young firms has declined.

Based on U.S. Census data, half of U.S. firms were 5 years old or younger in 1982; this share has steadily declined, reaching 32% in 2014 (Figure 8-30). Along with this decline in the share of young firms, there have been corresponding steady decreases in the share of new job creation and in the share of overall employment from young firms. Young firms accounted for 19% of employment in 1982, and the share declined to 10% by 2014. Although most startups fail and most of the startups that do survive do not grow, a small share of these fast-growing firms makes a disproportionately large contribution to job growth (Decker et al., 2014).

Although the factors behind these trends are not well understood, industry concentration and barriers to entry for inventors and entrepreneurs may be factors contributing to this decrease in dynamism in the U.S. economy. Foster and coauthors (2017) suggest that career paths of entrepreneurs and the activity of new firms are areas in which better data and analysis can help explain how innovation activity affects productivity.

FIGURE 8-30

Share of firms, job creation, and employment from firms 5 years old or younger: 1982–2015



Source(s)

U.S. Census Bureau, Business Dynamics Statistics, http://www.census.gov/ces/dataproducts/bds/data_firm.html; analysis presented in Decker R, Haltiwanger J, Jarmin R, Miranda J, The role of entrepreneurship in U.S. job creation and economic dynamism, *Journal of Economic Perspectives* 28(3):2–24 (2014).

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[1] See Bain & Company (2015) and Fung Global Retail and Technology (2017:4–6) for a discussion of the factors in the spike in venture capital financing.

[2] Another possibility is that the behavior of venture capital investors changed because fewer opportunities for attractive risky investments were available in the 2000s than in the 1990s.

[3] Source: PitchBook, http://pitchbook.com/.

[4] Snapchat's share prices rose more than 40% compared with its initial pricing on its IPO on 2 March 2017, resulting in a market capitalization of $33 billion.

[5] Source: PitchBook, http://pitchbook.com/.

[6] According to von Hippel (2017) , a user-developed innovation has been developed by the firm or the consumer that expects to benefit from using the product or service, rather than by the firm that expects to benefit from selling the product or service. A free innovation is one created outside of paid work time and not protected against sharing.

[7] The rate for the U.S. sample was 5.2% (i.e., 1 in 20 had developed an innovation as defined by the survey).

[8] When these technologies become widespread, there are complementarities between technical improvement for the GPTs and innovations in related application sectors that can lead to sustained aggregate economic growth. These gains, however, can take considerable time to emerge and may require significant and costly co-investments. From this perspective, the long process of diffusion of digitally networked GPTs has depressed the MFP growth rate in the near term but can increase it in the future.

[9] Branstetter and Sichel (2017) argue that improved measurement of prices for IT products would show multifactor productivity growing more quickly than in official statistics. The topic is not yet settled, including alternate estimates of productivity growth with adjustments for potential mismeasurement. Byrne, Fernald, and Reinsdorf (2016) adjust experimental growth measures for many of the identified issues and find that these adjustments would, overall, make the productivity slowdown worse instead of better.

Conclusion

This chapter focuses on the creation of inventions, knowledge transfer, and innovation through the introduction of new and improved goods and services. Many indicators in earlier chapters focus on S&E fields that flow into basic research and innovation.

Taken as a whole, *Indicators* chapters show a dynamic system, with global players large and small. Knowledge creation through skilled and trained workers, producing research discoveries and new technologies, fuel a fast-changing, knowledge-intensive global economy. Throughout, *Indicators* provides insights into inputs and activities of the U.S. innovation system in relation to the rest of the world. These topics include the development of human capital in S&E (Chapter 1, Chapter 2, and Chapter 3), R&D expenditures (Chapter 4 and Chapter 5), peer-reviewed research activities (Chapter 5), trade in knowledge-intensive industries (Chapter 6), and public perception of science (Chapter 7). The State Indicators data tool provides state-level indicators for many of these topics.

This chapter's indicators address invention, knowledge transfer, and innovation with high-quality data from a variety of sources, tracing through technology areas, industries, and product markets. While informative together, none provide a completely satisfactory innovation indicator alone. A key insight of this chapter is that a multiple-framework approach, when applied to complex and disparate data, can yield valuable insights into where and how innovation is taking place.

Looking forward, four main data challenges in the innovation system are (1) indicator coverage for all sectors of the economy, including households and entrepreneurs, government, and nonprofit institutions; (2) indicators of invention for unpatented inventions; (3) time series or other linked data to trace activities across time and geography, and finally, (4) indicators focused on impact and outcome measures for policy use.

Glossary

Definitions

European Union (EU): The EU comprises 28 member nations: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, and the United Kingdom. Unless otherwise noted, data on the EU include all 28 nations.

Federally funded research and development center (FFRDC): R&D-performing organizations that are exclusively or substantially financed by the federal government, to meet a particular R&D objective or, in some instances, to provide major facilities at universities for research and associated training purposes. Each FFRDC is administered by an industrial firm, a university, or a nonprofit institution.

Innovation: The implementation of a new or significantly improved product (good or service) or process, a new marketing method, or a new organization method in business practices, workplace organization, or external relations (OECD/Eurostat 2005).

Intangibles: Nonphysical factors that contribute to or are used to produce goods or services, or are intended to generate future benefits to the entities that control their use (Blair and Wallman 2001).

Mask works:A series of related images used as patterns in the construction of semiconductor chips.

Organisation for Economic Co-operation and Development (OECD): An international organization of 34 countries, headquartered in Paris, France. The member countries are Australia, Austria, Belgium, Canada, Chile, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Slovakia, Slovenia, South Korea, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States. Among its many activities, OECD compiles social, economic, and S&T statistics for all member and selected nonmember countries.

Technology transfer: The process by which technology or knowledge developed in one place or for one purpose is applied and exploited in another place for some other purpose. In the federal setting, technology transfer is the process by which existing knowledge, facilities, or capabilities developed under federal R&D funding are used to fulfill public and private needs.

Key to Acronyms and Abbreviations

ACS: American Competitiveness Survey

AFFOA: Advanced Functional Fabrics of America

ARM: Advanced Robotics for Manufacturing

ARMI: Advanced Regenerative Manufacturing Institute

ARPA-E: Advanced Research Projects Agency–Energy

AUTM: Association of University Technology Managers

BEA: Bureau of Economic Analysis

BLS: Bureau of Labor Statistics

BRDIS: Business R&D and Innovation Survey

CEMI: Clean Energy Manufacturing Initiative

CIS: Community Innovation Survey

CRADA: cooperative R&D agreement

DHS: Department of Homeland Security

DMDII: Digital Manufacturing and Design Innovation Institute

DOC: Department of Commerce

DOD: Department of Defense

DOE: Department of Energy

ED: Department of Education

EU: European Union

FFRDC: federally funded research and development center

FLC: Federal Laboratory Consortium for Technology Transfer

FY: fiscal year

GDP: gross domestic product

GPT: general purpose technology

HHS: Department of Health and Human Services

IACMI: Institute for Advanced Composites Manufacturing Innovation

ICT: information and communications technologies

IPC: International Patent Classification

IPO: initial public offering

ISO: International Organization for Standardization

IT: information technology

IUCRC: Industry-University Cooperative Research Centers Program

LIFT: Lightweight Innovations for Tomorrow

MEP: Hollings Manufacturing Extension Partnership

MFP: multifactor productivity

NAICS: North American Industry Classification System

NASA: National Aeronautics and Space Administration

NIIMBL: National Institute for Innovation in Manufacturing Biopharmaceuticals

NIST: National Institute of Standards and Technology

NPL: nonpatent literature

NSF: National Science Foundation

OECD: Organisation for Economic Co-operation and Development

R&D: research and development

RAPID: Rapid Advancement in Process Intensification Deployment

REMADE: Reducing Embodied-energy and Decreasing Emissions in Materials Manufacturing

ROW: rest of world

S&E: science and engineering

S&T: science and technology

SBA: U.S. Small Business Administration

SBIR: Small Business Innovation Research

SEP: standard essential patent

STTR: Small Business Technology Transfer

TFP: total factor productivity

UK: United Kingdom

USDA: Department of Agriculture

USPTO: U.S. Patent and Trademark Office

WIPO: World Intellectual Property Organization

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APPENDIX

Methodology

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Introduction

Science and Engineering Indicators (*Indicators*) contains data compiled from a variety of sources. This appendix explains the methodological and statistical criteria used to assess possible data sources for inclusion in *Indicators* and to develop statements about the data. It also provides basic information about how statistical procedures and reasoning are applied.

This appendix has four main sections, a glossary, and information on viewing the data sources for this report. The first section describes the considerations that are part of the selection process for information to be included in *Indicators*. The second section discusses the different sources of information (e.g., sample surveys, censuses, and administrative records) used in the report and provides details about each type. The third section discusses factors that can affect accuracy at all stages of the survey process. The fourth section discusses the statistical testing used to determine whether differences between sample survey-based estimates are *statistically significant*—that is, greater than could be expected by chance. The glossary covers statistical terms commonly used or referred to in the text. The appendix concludes by providing information on how to access the report's data sources, which can be viewed by chapter and by data provider.

Selection of Data Sources

Information is available from many sources, and it can vary in substantial ways. Several criteria guide the selection of data for *Indicators*:

Representativeness. Data should represent the entire national or international populations of interest and should reflect the heterogeneity of those populations. Data should be also available for the subdomains of interest covered in *Indicators* (e.g., the population of scientists and engineers or the topic of R&D spending by universities).

Relevance. Data should include indicators central to the functioning of the science and technology enterprise.

Timeliness. Data that are not part of a time series should be timely (i.e., they should be the most recent data available that meet the selection criteria).

Statistical and methodological quality. Survey methods used to collect data should provide sufficient assurance that survey estimates are robust and that statements based on statistical analysis of the data are valid and reliable. Nonsurvey data, such as administrative records, or data from other third-party sources should similarly be assessed for quality—that is, fitness for use. All external data should be properly sourced and cited. Data included in *Indicators* must be of high quality. Known limitations of the external data must be clearly stated. Data quality has several characteristics. Some key dimensions of quality include the following.

> **Validity.** Data have *validity* if they accurately measure the phenomenon they are supposed to represent.
>
> **Reliability.** Data have *reliability* if similar results would be produced if the same measurement or procedure were performed multiple times on the same population.
>
> **Accuracy.** Data are *accurate* if estimates from the data do not widely deviate from the true population value.

Data that are collected by U.S. government agencies and that are products of the federal statistical system meet the rigorous statistical and methodological criteria described above. Unless otherwise indicated, these data are representative of the nation as a whole and of the demographic, organizational, or geographic subgroups that constitute it.

For data collected by governments in other countries and by nongovernment sources, including private survey firms and academic researchers, methodological information is examined to assess conformity with the criteria that U.S. federal agencies typically use. Government statistical agencies in the developed world cooperate extensively both in developing data-quality standards and in improving international comparability for key data, and these agencies ensure that the methodological information about the data generated by this international statistical system is relatively complete.

Often, methodological information about data from nongovernmental sources and from governmental agencies outside the international statistical system is less well documented. These data must meet basic scientific standards for representative sampling of survey respondents and for adequate and unbiased coverage of the population under study. The resulting measurements must be sufficiently relevant and meaningful to warrant publication despite methodological uncertainties that remain after the documentation has been scrutinized.

Many data sources that contain pertinent information about a segment of the S&E enterprise are not cited in *Indicators* because their coverage of the United States is partial in terms of geography, incomplete in terms of segments of the population, or otherwise not representative. For example, data may be available for only a limited number of states, or studies may be based on populations not representative of the United States as a whole. Similarly, data for other countries should cover and be representative of the entire country. In some cases, data that have limited coverage or are otherwise insufficiently representative are referenced in sidebars.

Types of Data Sources

Much of the data cited in *Indicators* comes from surveys. Surveys strive to measure characteristics of target populations. To generalize survey results correctly to the population of interest, a survey's *target population* must be rigorously defined, and the criteria determining membership in the population must be applied consistently in determining which units to include in the survey. After a survey's target population has been defined, the next step is to establish a list of all members of that target population (i.e., a *sampling frame*). Members of the population must be selected from this list using accepted statistical methods so that it will be possible to generalize from the sample to the population as a whole. Surveys sometimes sample from lists that, to varying extents, omit members of the target population because complete lists are typically unavailable.

Some surveys are censuses (also known as *universe surveys*), in which the survey attempts to obtain data for all population units. The decennial census, in which the target population is all U.S. residents, is the most familiar census survey. *Indicators* uses data from the Survey of Earned Doctorates, an annual census of individuals who earn research doctorates from accredited U.S. institutions, for information about the numbers and characteristics of new U.S. doctorate holders.

Other surveys are *sample surveys*, in which data are obtained for only a portion of the population units. Samples can be drawn using either probability-based or nonprobability-based sampling procedures. A sample is a *probability sample* if each unit in the sampling frame has a known, nonzero probability of being selected for the sample. Probability samples are preferred because their use allows the computation of measures of precision and the subsequent statistical evaluation of inferences about the survey population. An example of a sample survey is the National Survey of College Graduates (NSCG). The NSCG gathers data on the nation's college graduates, with particular focus on those educated or employed in an S&E field. In *nonprobability sampling*, the sample is drawn with an unknown probability of selection. Polls that elicit responses from self-selected individuals, such as opt-in Internet surveys or phone-in polls, are examples of nonprobability sample surveys. Except for some Asian surveys referenced in Chapter 7, sample surveys included in *Indicators* use probability sampling.

Surveys may be conducted of individuals or of organizations, such as businesses, universities, or government agencies. Surveys of individuals are referred to as *demographic surveys*. Surveys of organizations are often referred to as *establishment surveys.* An example of an establishment survey used in *Indicators* is the Higher Education Research and Development Survey.

Surveys may be longitudinal or cross-sectional. In a *longitudinal survey*, the same sample members are surveyed repeatedly over time. The primary purpose of longitudinal surveys is to investigate changes over time. The Survey of Doctorate Recipients is a sample survey of individuals who received research doctorates from U.S. institutions. The survey was originally designed to produce cross-sectional estimates, but the data have also been adapted by researchers to conduct longitudinal studies. *Indicators* uses results from this survey to analyze the careers of doctorate holders.

Cross-sectional surveys provide a snapshot at a given point in time. When conducted periodically, cross-sectional surveys produce repeated snapshots of a population, also enabling analysis of how the population changes over time. However, because the same individuals or organizations are not included in each survey cycle, cross-sectional surveys cannot, in general, track changes for specific individuals or organizations. National and international assessments of student achievement in K–12 education, such as those discussed in Chapter 1, are examples of repeated cross-sectional surveys. Most of the surveys cited in *Indicators* are conducted periodically, although the frequency with which they are conducted varies.

Surveys can be self- or interviewer-administered, and they can be conducted using a variety of modes (e.g., postal mail, telephone, the Web, e-mail, or in person). Many surveys are conducted using more than one mode. The NSCG is an example of a multimode survey. It is conducted primarily via the Web; potential participants who do not respond to the questionnaire are contacted via telephone.

Some of the data in *Indicators* come from *administrative records* (data collected for the purpose of administering various programs). Examples of data drawn directly from administrative records in *Indicators* include patent data from the records of government patent offices; bibliometric data on publications in S&E journals, compiled from information collected and published by the journals themselves; and data on foreign S&E workers temporarily in the United States, drawn from the administrative records of immigration agencies.

Many of the establishment surveys that *Indicators* uses depend heavily, although indirectly, on administrative records. Universities and corporations that respond to surveys about their R&D activities often use administrative records developed for internal management or income tax reporting purposes to respond to these surveys.

Data Accuracy

Accurate information is a primary goal of censuses and sample surveys. Accuracy can be defined as the extent to which results deviate from the true values of the characteristics in the target population. Statisticians use the term “error” to refer to this deviation. Good survey design seeks to minimize survey error.

Statisticians usually classify the factors affecting the accuracy of survey data into two categories: nonsampling and sampling errors. *Nonsampling error* applies to administrative records and surveys, including censuses, whereas *sampling error* applies only to sample surveys.

Nonsampling Error

Nonsampling error refers to error related to the design, data collection, and processing procedures. Nonsampling error may occur at each stage of the survey process and is often difficult to measure. The sources of nonsampling error in surveys have analogues for administrative records: the purposes for and the processes through which the records are created affect how well the records capture the concepts of interest of relevant populations (e.g., patents, journal articles, immigrant scientists and engineers). A brief description of five sources of nonsampling error follows. For convenience, the descriptions refer to samples, but they also apply to censuses and administrative records.

Specification error. Survey questions often do not perfectly measure the concept for which they are intended as indicators. For example, the number of patents does not perfectly quantify the amount of invention.

Coverage error. The sampling frame, the listing of the target population members used for selecting survey respondents, may be inaccurate or incomplete. If the frame has omissions, duplications, or other flaws, the survey is less representative because coverage of the target population is inaccurate. Frame errors often require extensive effort to correct.

Nonresponse error. Nonresponse error can occur if not all members of the sample respond to the survey. *Response rates* indicate the proportion of sample members that respond to the survey. Response rate is not always an indication of nonresponse error.

Nonresponse can cause *nonresponse bias*, which occurs when the people or establishments that respond to a question, or to the survey as a whole, differ in systematic ways from those who do not respond. For example, in surveys of national populations, complete or partial nonresponse is often more likely among lower-income or less-educated respondents. Evidence of nonresponse bias is an important factor in decisions about whether survey data should be included in *Indicators*.

Managers of high-quality surveys, such as those in the U.S. federal statistical system, do research on nonresponse patterns to assess whether and how nonresponse might bias survey estimates. *Indicators* notes instances where reported data may be subject to substantial nonresponse bias.

Measurement error. There are many sources of measurement error, but respondents, interviewers, mode of administration, and survey questionnaires are the most common. Knowingly or unintentionally, respondents may provide incorrect information. Interviewers may influence respondents' answers or record their answers incorrectly. The questionnaire can be a source of error if there are ambiguous, poorly worded, or confusing questions, instructions, or terms or if the questionnaire layout is confusing.

In addition, the records or systems of information that a respondent may refer to, the mode of data collection, and the setting for the survey administration may contribute to measurement error. Perceptions about whether data will be treated as confidential may affect the accuracy of survey responses to sensitive questions, such as those about business profits or personal incomes.

Processing error. Processing errors include errors in recording, checking, coding, and preparing survey data to make them ready for analysis.

Sampling Error

Sampling error is the most commonly reported measure of a survey's precision. Unlike nonsampling error, sampling error can be quantitatively estimated in most scientific sample surveys.

Sampling error is the uncertainty in an estimate that results because not all units in the population are measured. Chance is involved in selecting the members of a sample. If the same, random procedures were used repeatedly to select samples from the population, numerous samples would be selected, each containing different members of the population with different characteristics. Each sample would produce different population estimates. When there is great variation among the samples drawn from a given population, the sampling error is high, and there is a large chance that the survey estimate is far from the true population value. In a census, because the entire population is surveyed, there is no sampling error, but nonsampling errors may still exist.

Sampling error is reduced when samples are large, and most of the surveys used in *Indicators* have large samples. Typically, sampling error is a function of the sample design and size, the variability of the measure of interest, and the methods used to produce estimates from the sample data.

Sampling error associated with an estimate is often measured by the coefficient of variation or margin of error, both of which are measures of the amount of uncertainty in the estimate.

Statistical Testing of Sample Survey Data

Statistical tests can be used to determine whether differences observed in sample survey data are "real" differences in the population. Differences that are termed *statistically significant* are likely to occur in the target population. When *Indicators* reports statements about differences on the basis of sample surveys, the differences are statistically significant at least at the 10% level. This means that, if there were no true difference in the population, the chance of drawing a sample with the observed or greater difference would be no more than 10%.

A statistically significant difference is not necessarily large, important, or significant in the usual sense of the word. It is simply a difference that is unlikely to be caused by chance variation in sampling. With the large samples common in *Indicators* data, extremely small differences can be found to be statistically significant. Conversely, quite large differences may not be statistically significant if the sample or population sizes of the groups being compared are small. Occasionally, apparently large differences are noted in the text as not being statistically significant to alert the reader that these differences may have occurred by chance.

Numerous differences are apparent in every table in *Indicators* that reports sample data. The tables permit comparisons between different groups in the survey population and in the same population in different years. It would be impractical to test and indicate the statistical significance of all possible comparisons in tables involving sample data.

As explained in the section About Science and Engineering Indicators, *Indicators* presents indicators. It does not model the dynamics of the S&E enterprise, although analysts could construct models using the data in *Indicators*. Accordingly, *Indicators* does not make use of statistical procedures suitable for causal modeling and does not compute effect sizes for models that might be constructed using these data.

Glossary

Most glossary definitions are based on U.S. Office of Management and Budget, Office of Statistical Policy (2006), *Standards and Guidelines for Statistical Surveys* (https://unstats.un.org/unsd/dnss/docs-nqaf/USA_standards_stat_surveys.pdf), and U.S. Census Bureau (2006), *Organization of Metadata, Census Bureau Standard Definitions for Surveys and Census Metadata*. In some cases, glossary definitions are somewhat more technical and precise than those in the text, where fine distinctions are omitted to improve readability.

Accuracy: Accuracy is the difference between the estimate and the true parameter value.

Administrative records: Microdata records collected for the purpose of carrying out various programs (e.g., tax collection). Unlike survey data, administrative data were not originally collected for statistical purposes.

Bias: Systematic deviation of the survey estimated value from the true population value. Bias refers to systematic errors that can occur with any survey under a specific design.

Census: A data collection that seeks to obtain data directly from all eligible units in the entire target population. It can be considered a sample with a 100% sampling rate. A census may use data from administrative records for some units rather than direct data collection.

Coverage: Extent to which all elements on a frame list are members of the population and to which every element in a population appears on the frame list once and only once.

Coverage error: Discrepancy between statistics calculated on the frame population and the same statistics calculated on the target population. *Undercoverage* errors occur when target population units are missed during frame construction, and *overcoverage* errors occur when units are duplicated, enumerated incorrectly, or are not part of the target population.

Cross-sectional sample survey: Based on a representative sample of respondents drawn from a population at a particular point in time.

Estimate: A numerical value for a population parameter derived from information collected from a survey or other sources.

Estimation error: Difference between a survey estimate and the true value of the parameter in the target population.

Frame: A mapping of the universe elements (i.e., sampling units) onto a finite list (e.g., the population of schools on the day of the survey).

Item nonresponse: Occurs when a respondent fails to respond to one or more relevant items on a survey.

Longitudinal sample survey: Follows the experiences and outcomes over time of a representative sample of respondents (i.e., a cohort).

Measurement error: Difference between observed values of a variable recorded under similar conditions and some fixed true value (e.g., errors in reporting, reading, calculating, or recording a numerical value).

Nonresponse bias: Occurs when the observed value deviates from the population parameter due to systematic differences between respondents and nonrespondents. Nonresponse bias may occur as a result of not obtaining 100% response from the selected units.

Nonresponse error: Overall error observed in estimates caused by differences between respondents and nonrespondents. It consists of a variance component and nonresponse bias.

Nonsampling error: Includes specification errors and measurement errors due to interviewers, respondents, instruments, and mode; nonresponse error; coverage error; and processing error.

Parameter: An unknown, quantitative measure (e.g., total revenue, mean revenue, total yield, or number of unemployed people) for the entire population or for a specified domain of interest.

Population: The set of persons or organizations to be studied, which may not be of finite size.

Precision of survey results: How closely results from a sample can reproduce the results that would be obtained from a complete count (i.e., census) conducted using the same techniques. The difference between a sample result and the result from a complete census taken under the same conditions is an indication of the precision of the sample result.

Probabilistic methods: Any of a variety of methods for survey sampling that gives a known, nonzero probability of selection to each member of a target population. The advantage of probabilistic sampling methods is that sampling error can be calculated. Such methods include random sampling, systematic sampling, and stratified sampling. They do not include convenience sampling, judgment sampling, quota sampling, and snowball sampling.

Reliability: Degree to which a measurement technique would yield the same result each time it is applied. A measurement can be both reliable and inaccurate.

Response bias: Deviation of the survey estimate from the true population value due to measurement error from the data collection. Potential sources of response bias include the respondent, the instrument, the mode of data collection, and the interviewer.

Response rates: These measure the proportion of the sample frame represented by the responding units in each study.

Sample design: Refers to the combined target population, frame, sample size, and sample selection methods.

Sample survey: A data collection that obtains data from a sample of the frame population.

Sampling error: Error that occurs because all members of the frame population are not measured. It is associated with the variation in samples drawn from the same frame population. The sampling error equals the square root of the variance.

Standard error: Standard deviation of the sampling distribution of a statistic. Although the standard error is used to estimate sampling error, it includes some nonsampling error.

Statistical significance: Attained when a statistical procedure applied to a set of observations yields a *p*-value that exceeds the level of probability at which it is agreed that the null hypothesis will be rejected.

Target population: Any group of potential sample units or individuals, businesses, or other entities of interest.

Unit nonresponse: Occurs when a respondent fails to respond to all required response items (i.e., fails to complete or return a data collection instrument).

Universe survey: Involves the collection of data covering all known units in a population (i.e., a census).

Validity: Degree to which an estimate is likely to be true and free of bias (systematic errors).

View Data Sources

The complete list of data sources used in this volume can be found in the Data Sources section (https://www.nsf.gov/statistics/2018/nsb20181/data/sources). Data sources can be viewed by chapter and by data provider.

Errata

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Science and Engineering Indicators 2018 Errata

The following issues were discovered and corrected after the publication of *Science and Engineering Indicators 2018*. To report an error, please send an email to ncsesweb@nsf.gov. This page was last updated on 21 March 2018.

Chapter 2

Owing to a composition issue, Appendix Table 2-20 was missing the data for 2015. The table has been corrected in all formats. (21 March 2018)

Chapter 5

In the discussion on EPSCoR, the text used the historical name of the program. The American Innovation and Competitiveness Act of 2017 changed the program's name from the Experimental Program to Stimulate Competitive Research to the Established Program to Stimulate Competitive Research. The program name has been updated throughout, and a note regarding the name change has been added to the EPSCoR sidebar in Chapter 5. (7 February 2018)