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.

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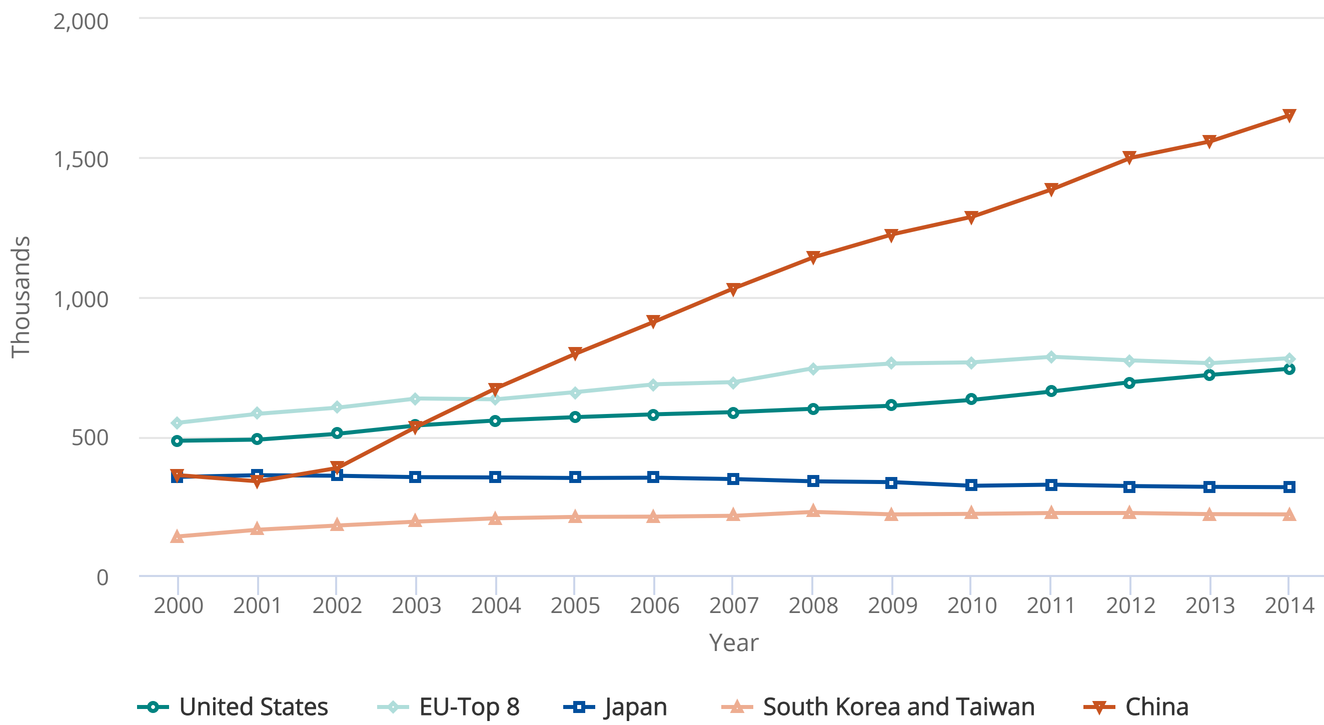
FIGURE O-1

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,

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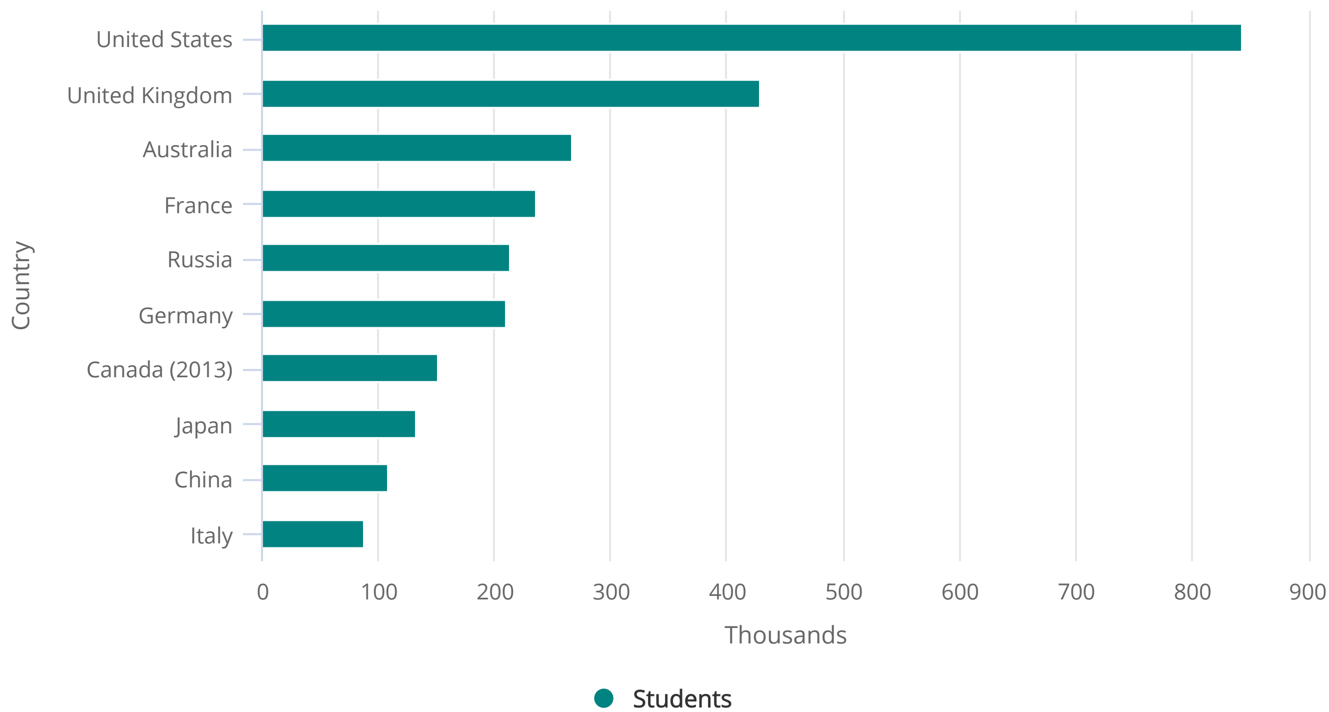
international students accounted for a considerable increase over time in U.S. higher education degree awards in S&E fields. Yet, due in part to efforts by other countries to attract more foreign students, the share of the world's internationally mobile students enrolled in the United States fell from 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.

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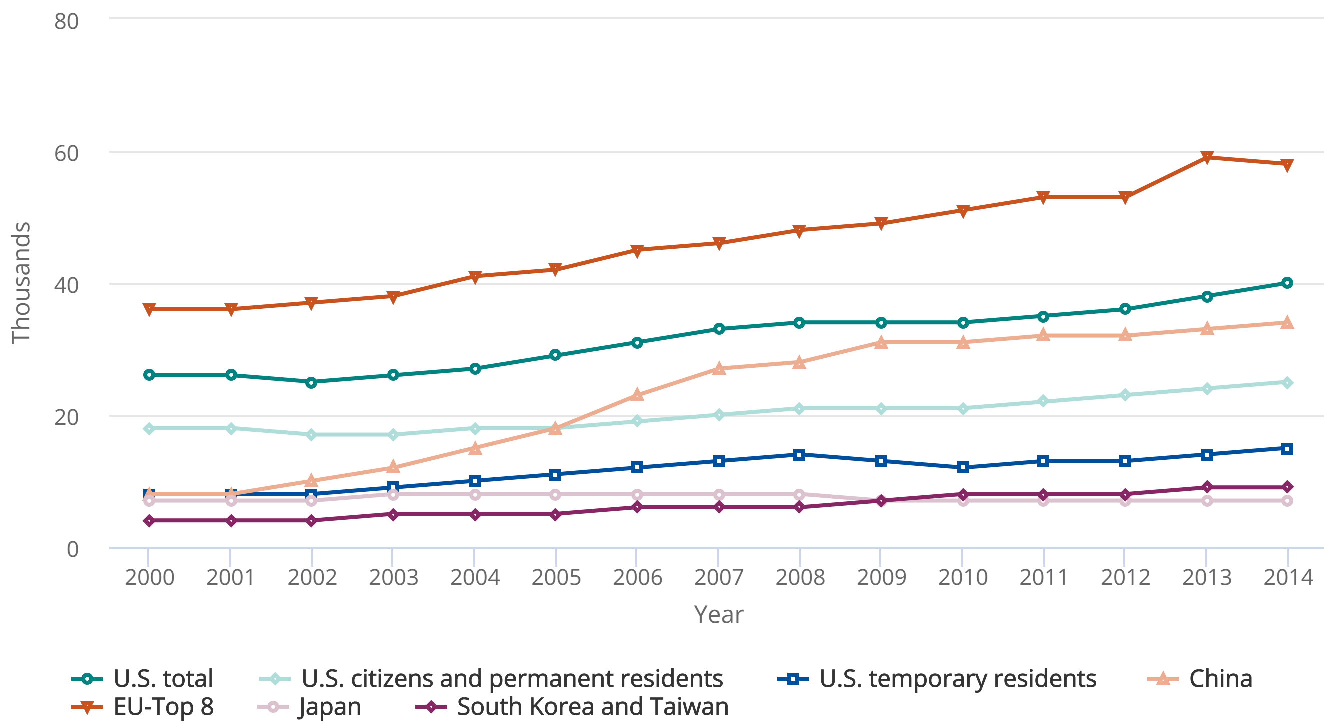
FIGURE O-3

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).

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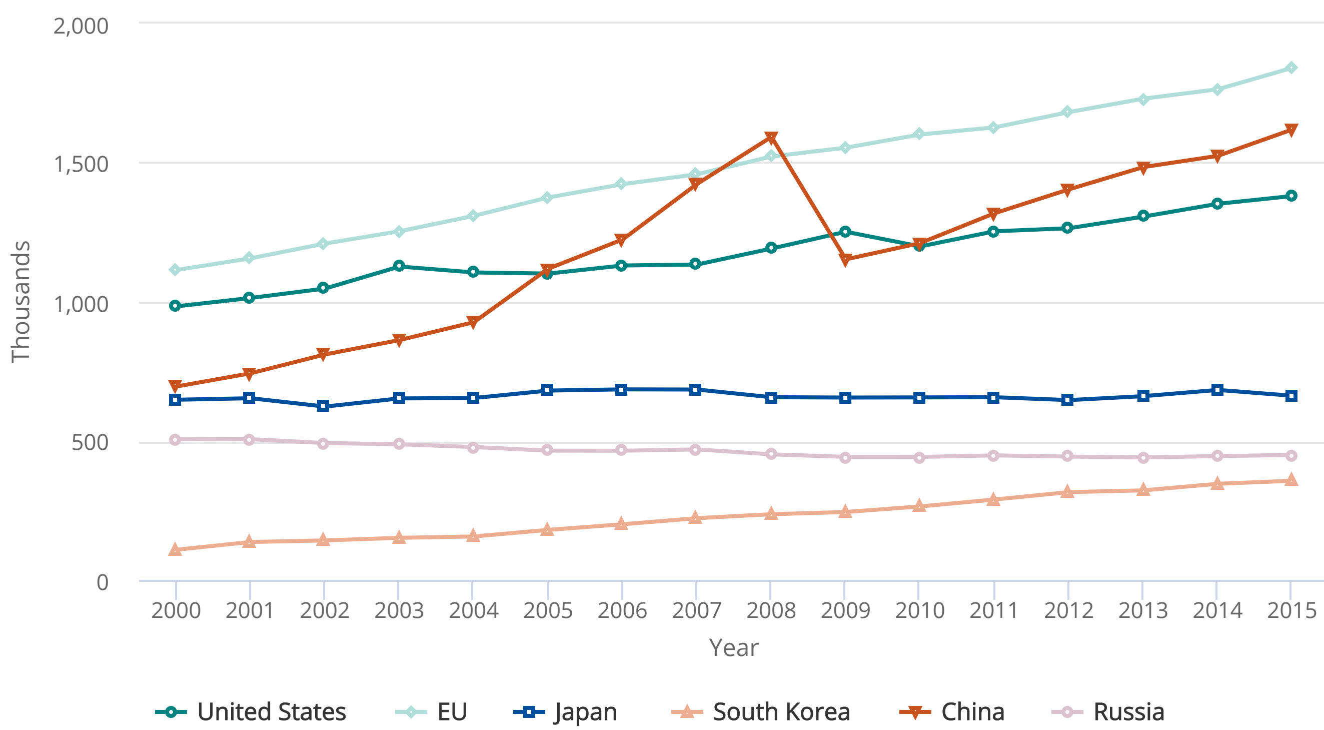
FIGURE O-4

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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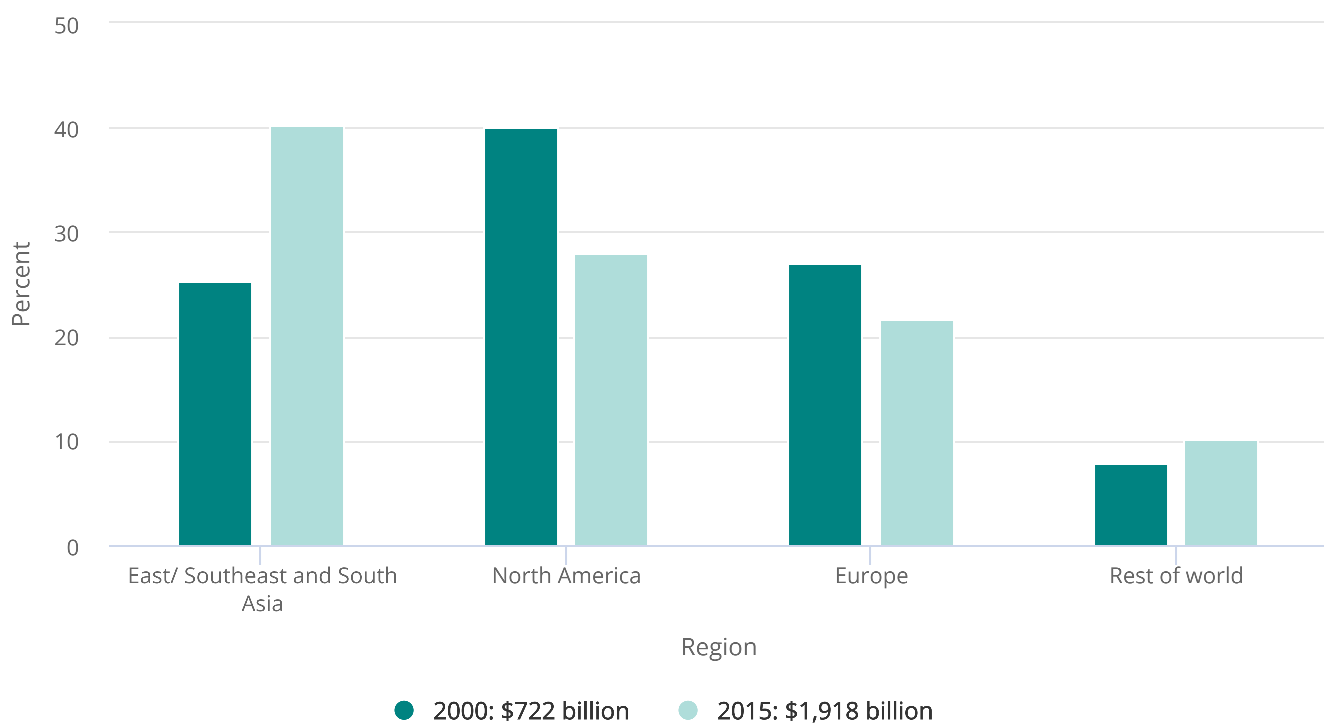
FIGURE O-5

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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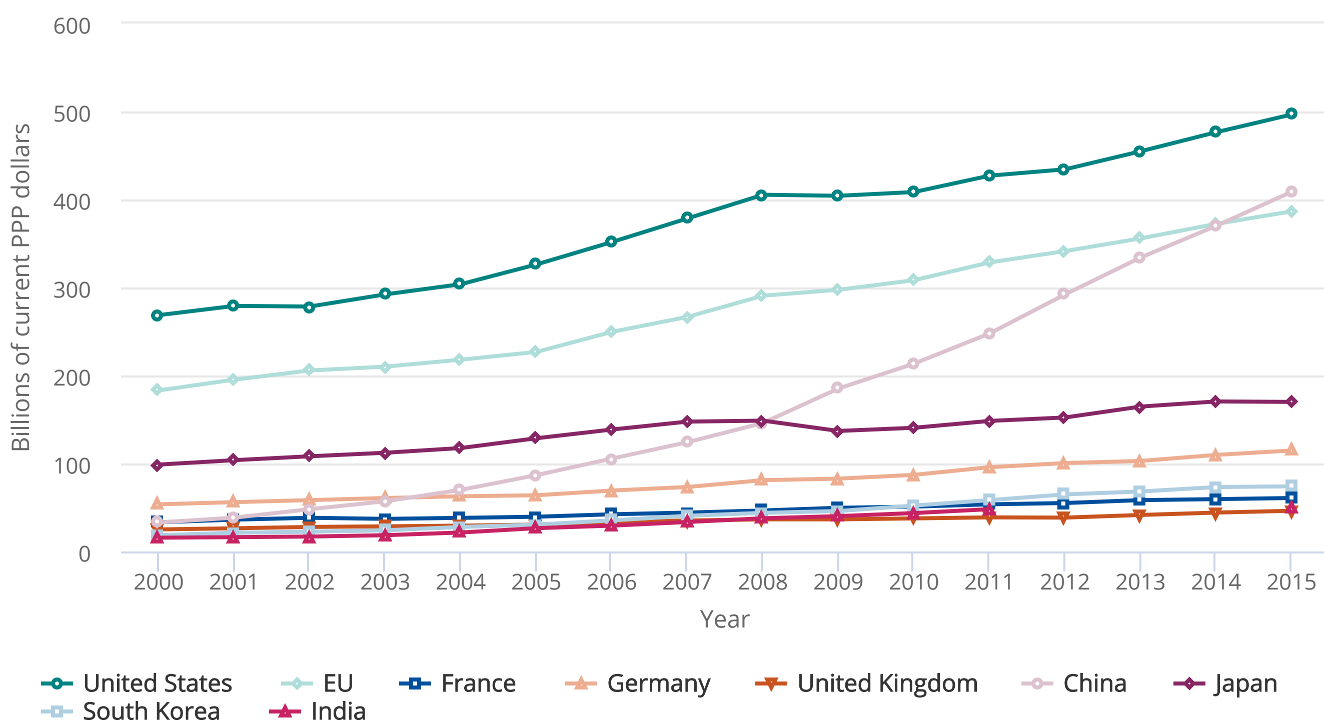
FIGURE O-6

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.

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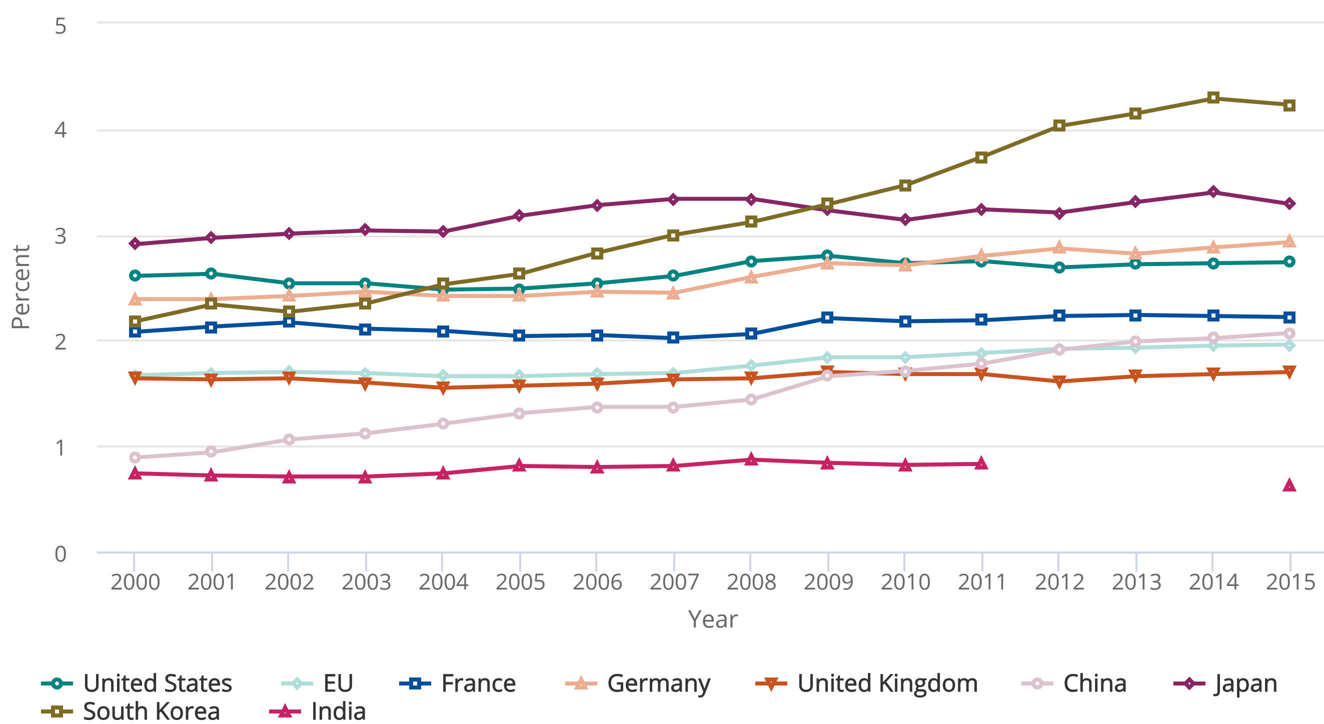
FIGURE O-7

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.

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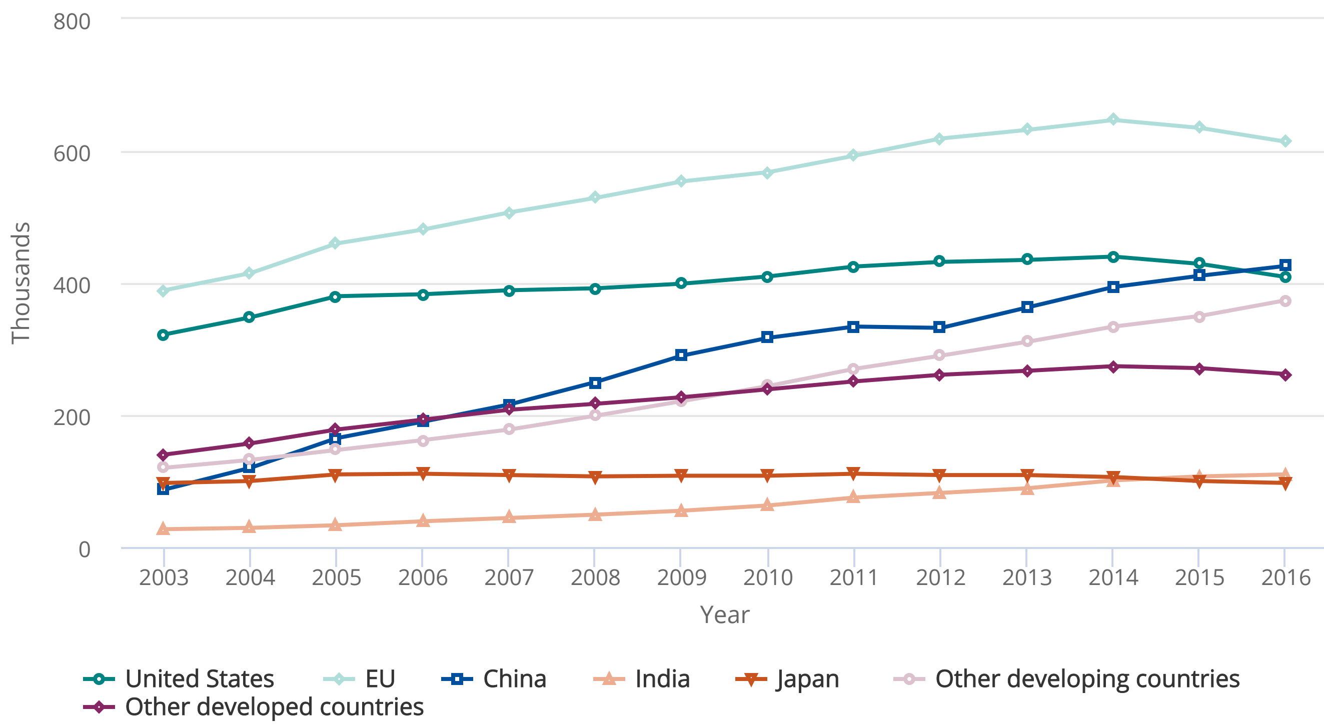
FIGURE O-8

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

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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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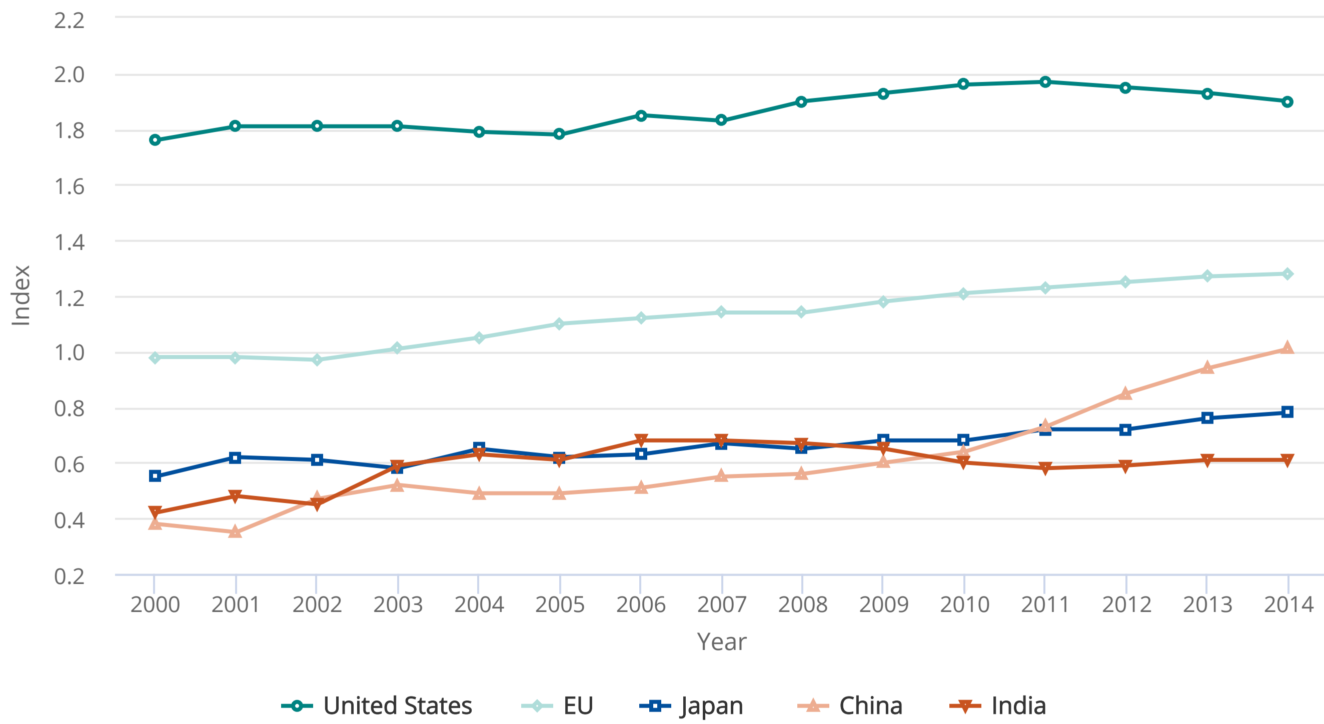
FIGURE O-9

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.

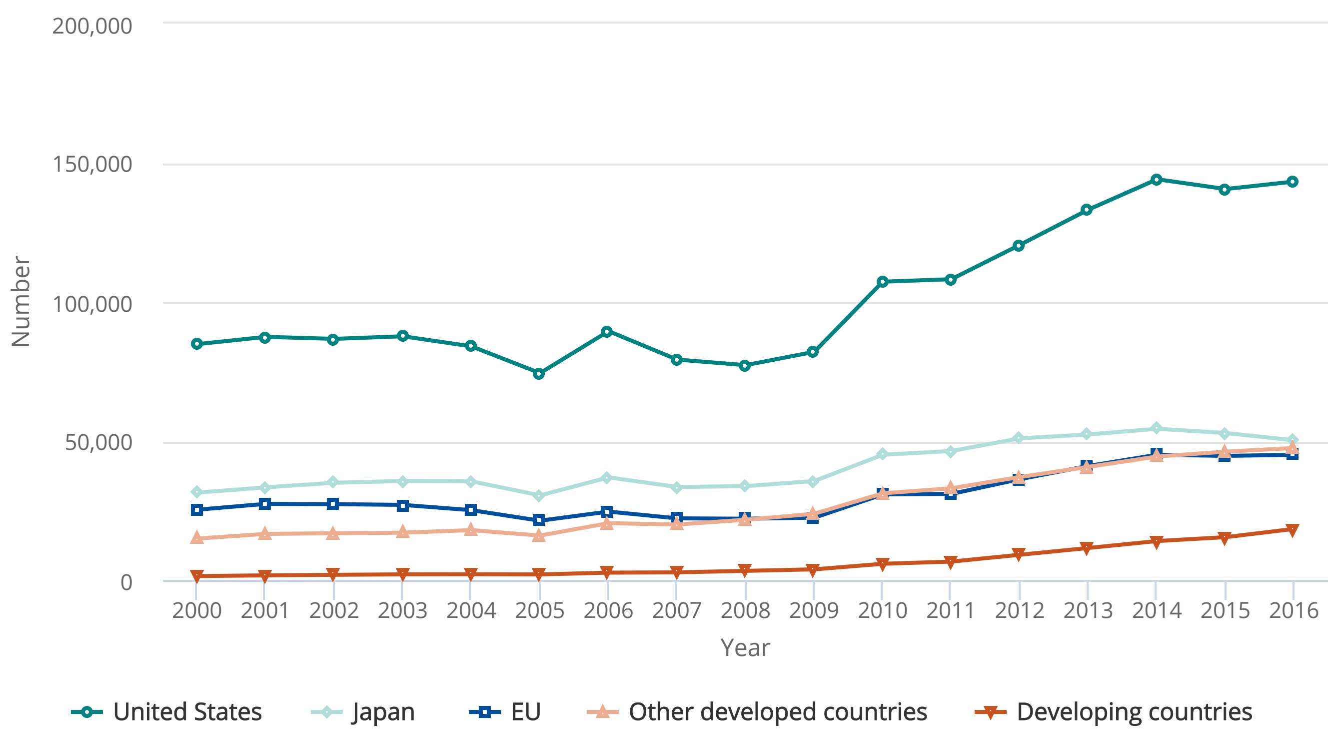
Patenting confers the rights of property to novel, useful, and nonobvious inventions for a specified period. Although the propensity to patent varies across technology areas—and many patents do not become commercialized or lead to practical innovations—patent grants and applications are one indicator 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.

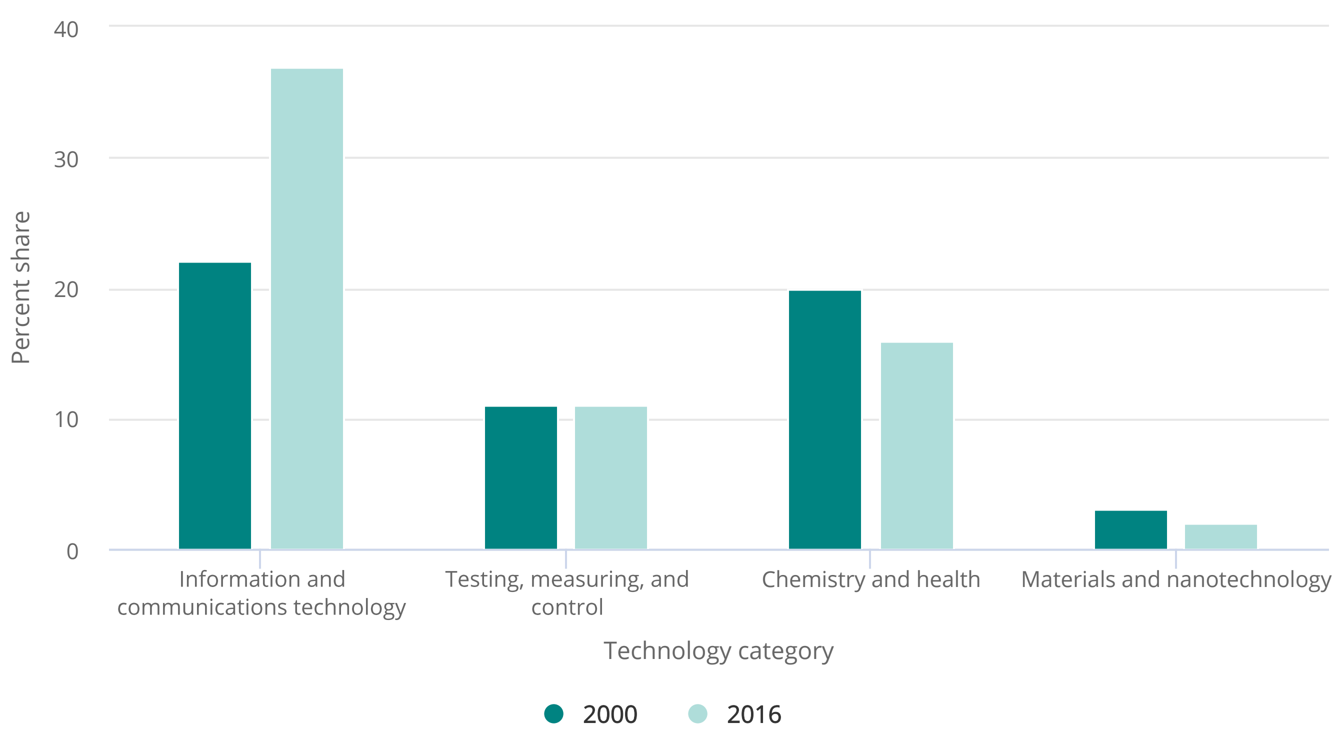
Science and Engineering Indicators 2018

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.

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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

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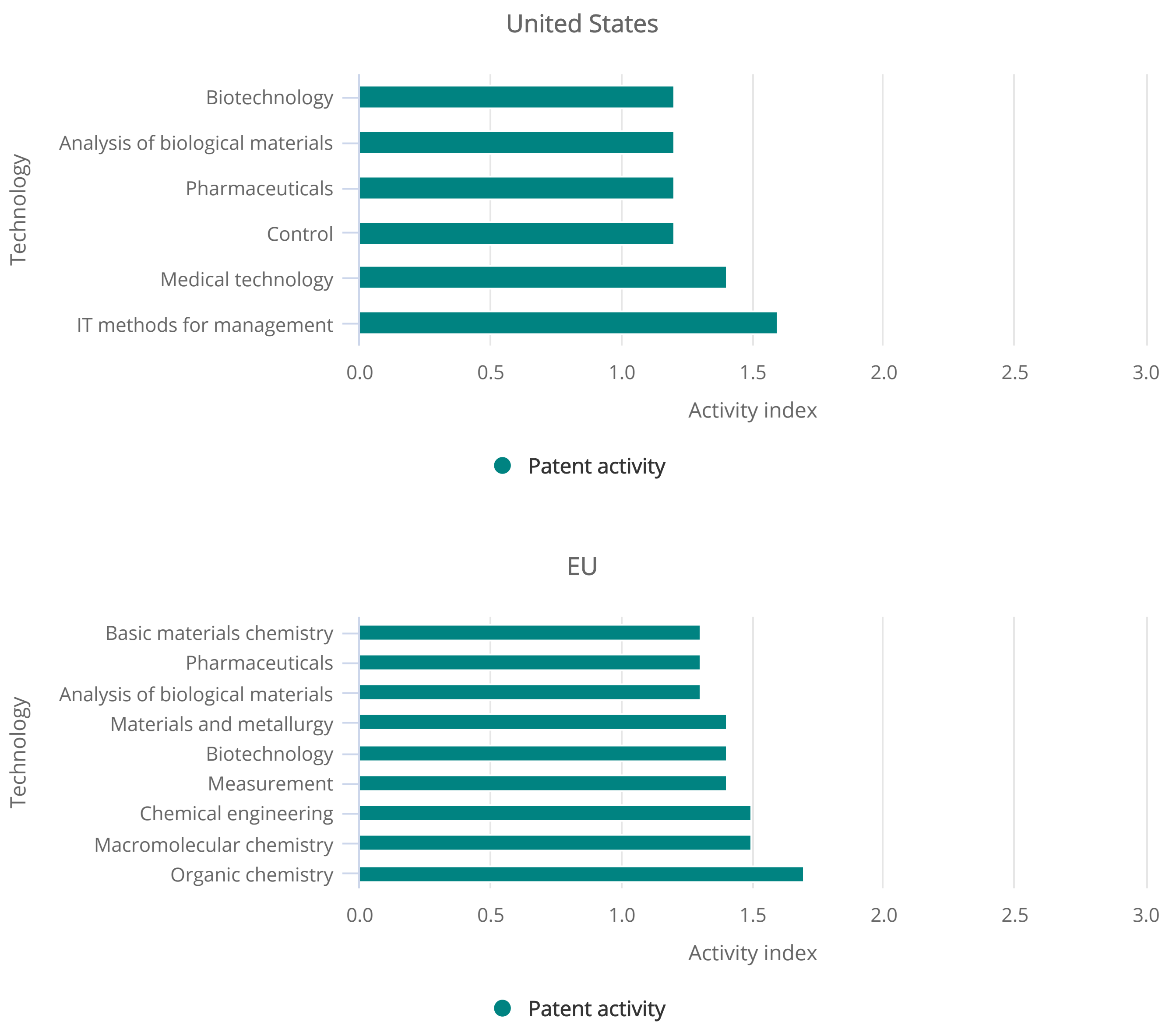
patents awarded to U.S. inventors have a particularly high concentration in the ICT area of information technology (IT) methods for management, a field that includes special-purpose software for business management. This U.S. specialization in part reflects patent rule differences within each country. 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



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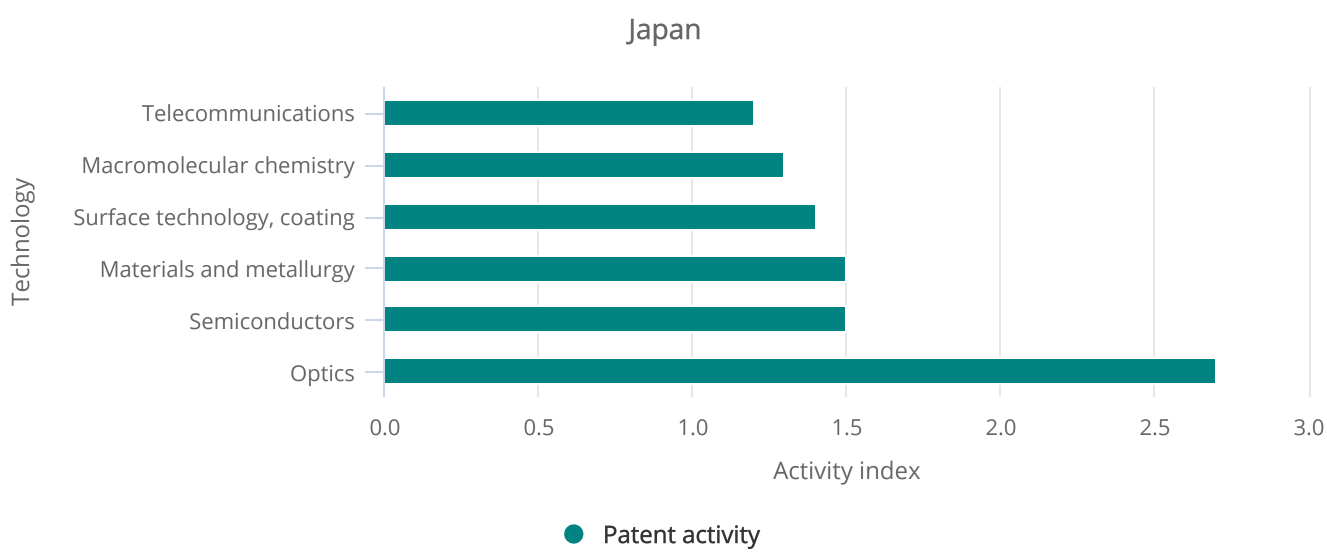


EU = European Union; IT = information technology.

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)

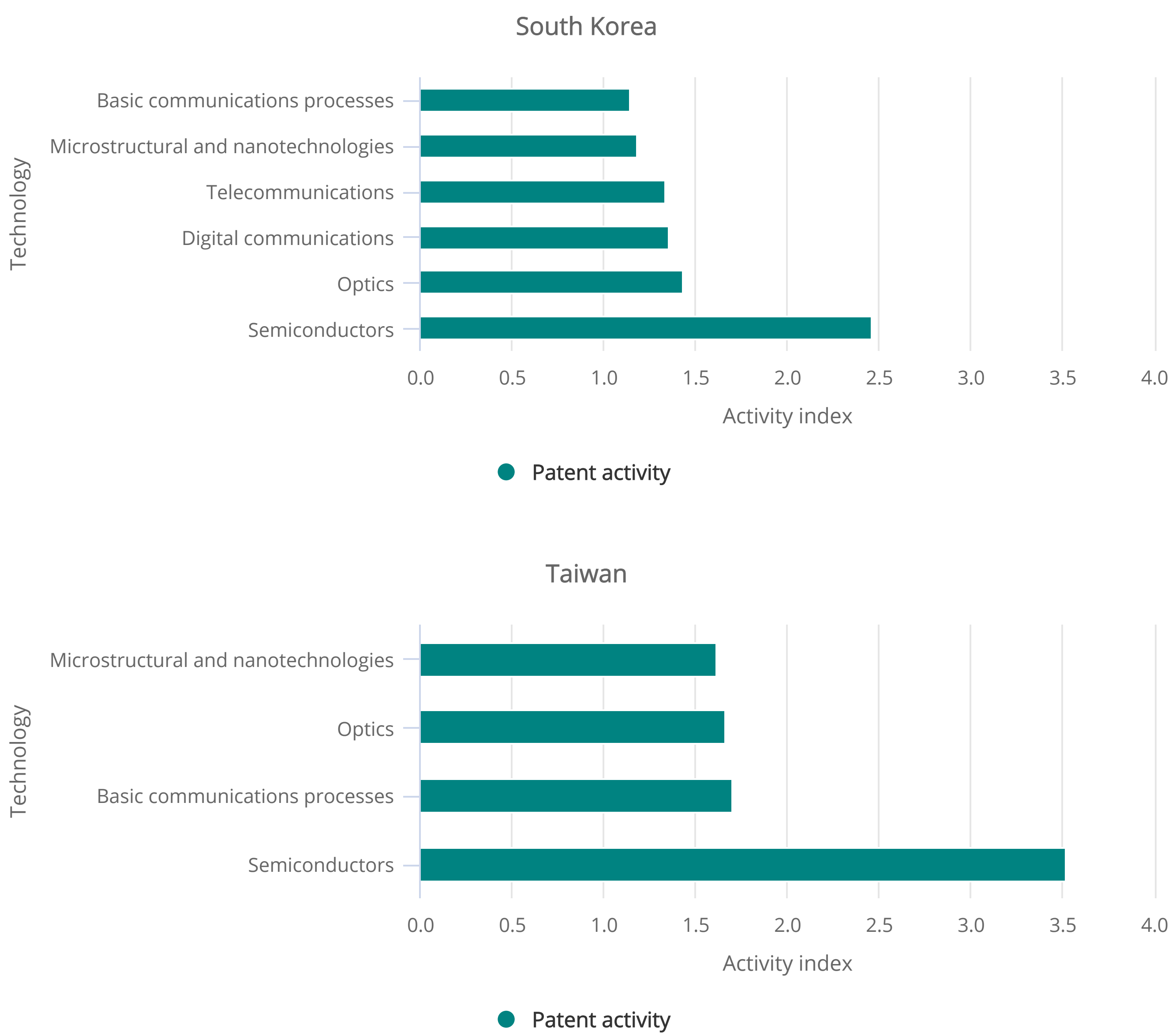
Science-Metrix; PatentsView; SRI International.

Science and Engineering Indicators 2018

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



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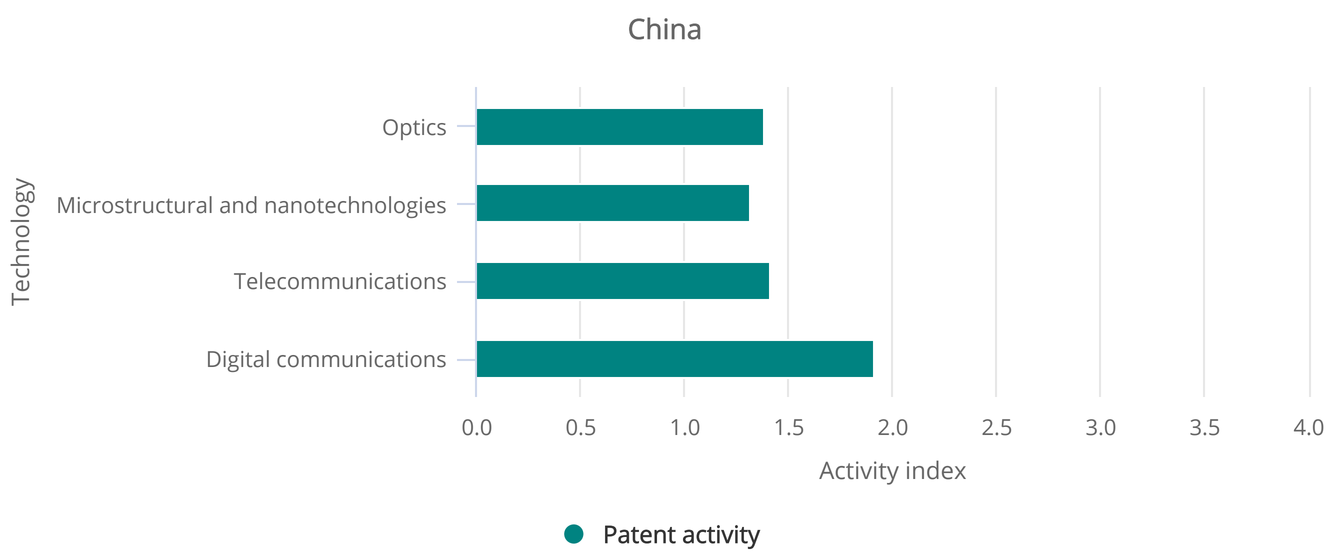

Note(s)

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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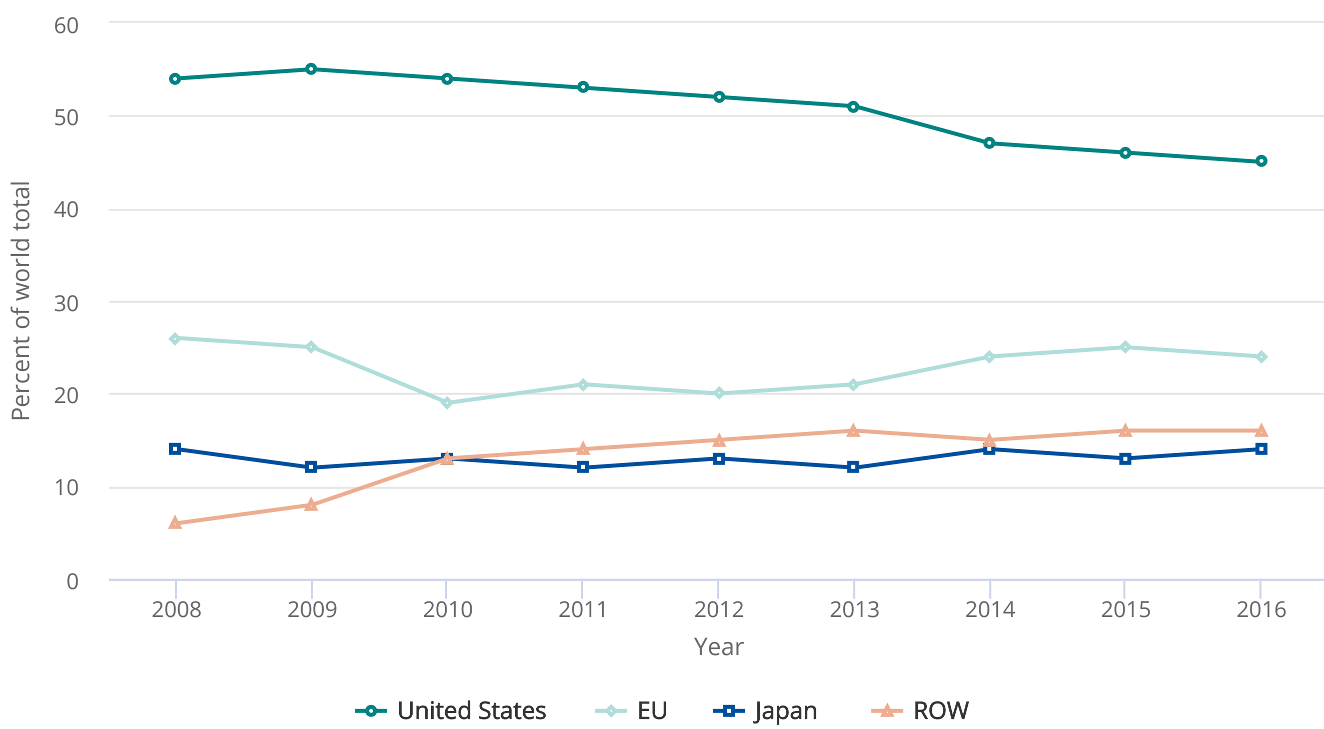
Knowledge transfer, including the transfer and dissemination of technology from inventors to users, is a critical component of the innovation system. International transactions allow tracking of the market-based diffusion of technology and innovation across international boundaries. One measure of such 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.

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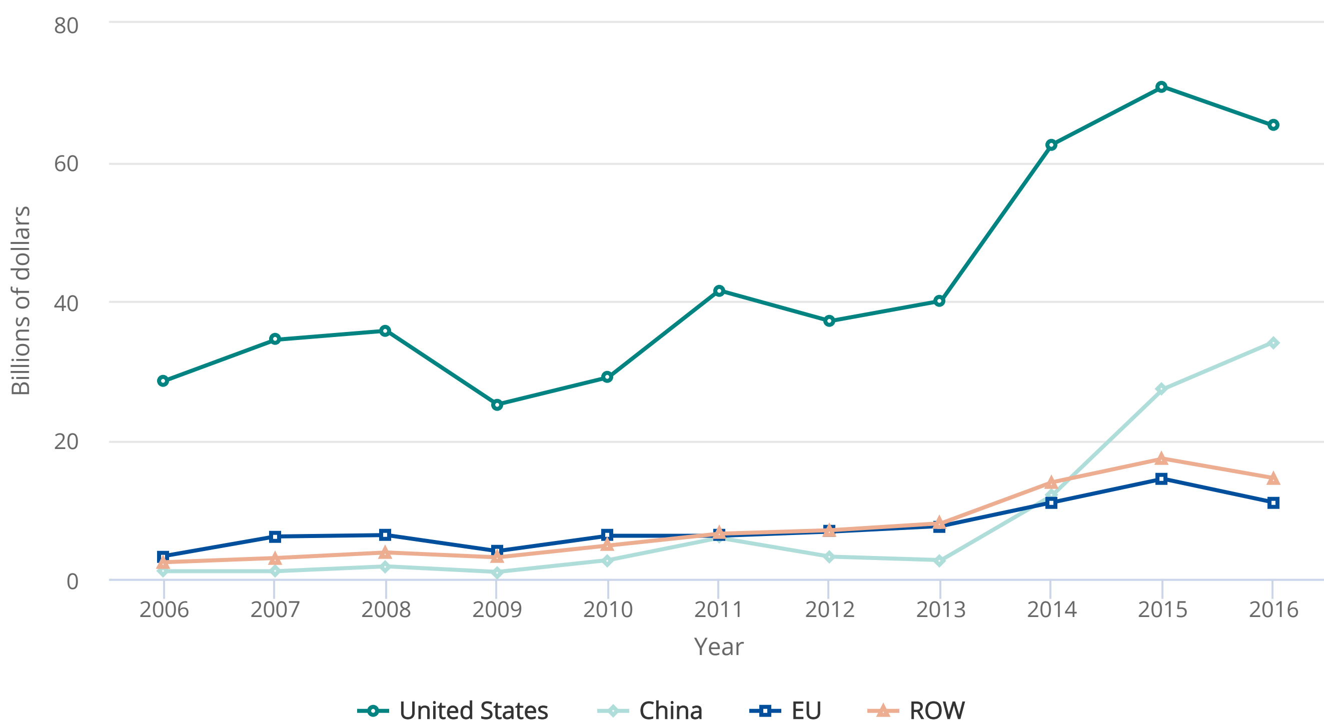
Another essential component of the translation of inventions into innovations and practical use is access to financing. Developing and commercializing new and emerging technology is inherently risky, and financial support can provide insurance against some of this uncertainty. Venture capital investment 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%.

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

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/.

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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.

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[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.

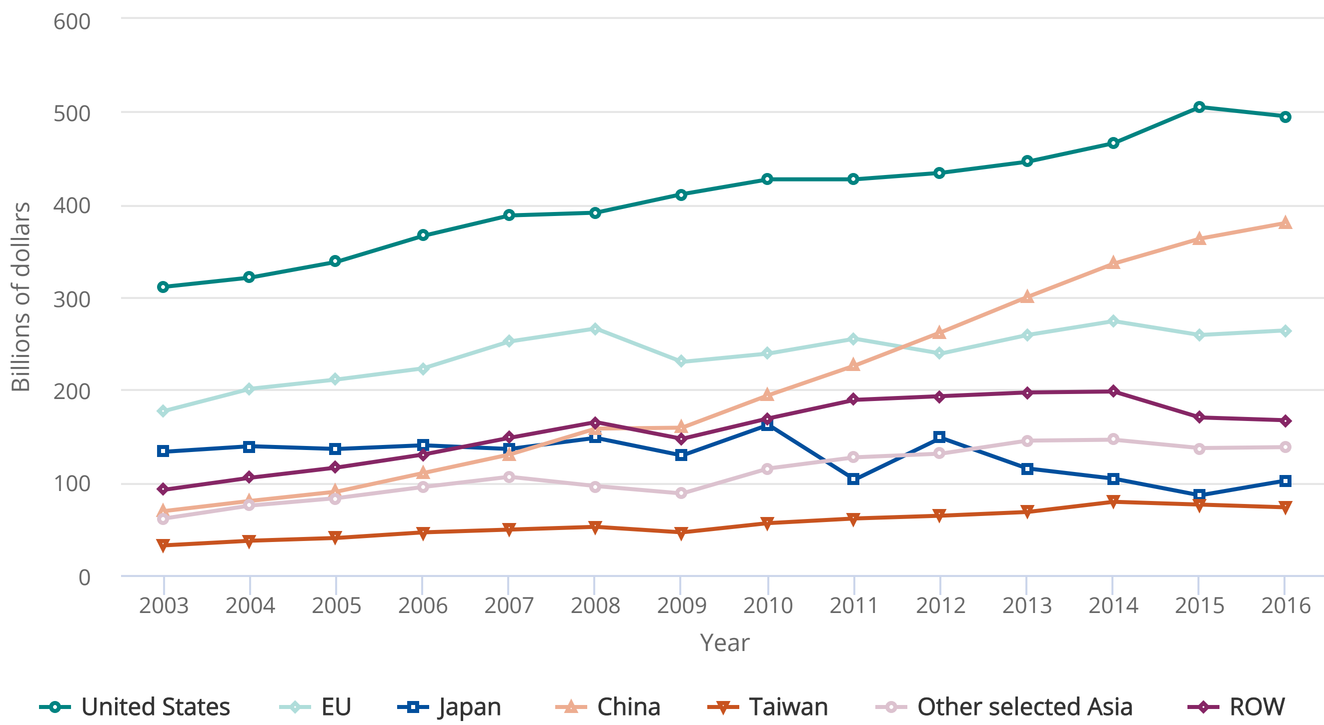
The technology-intensive manufacturing industries are the most globalized among the KI industries. International trade and an interconnected global supply chain tie these KI industries across the globe and reflect the interdependence and the extent of globalization in the production process. For example, 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.

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

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.

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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).

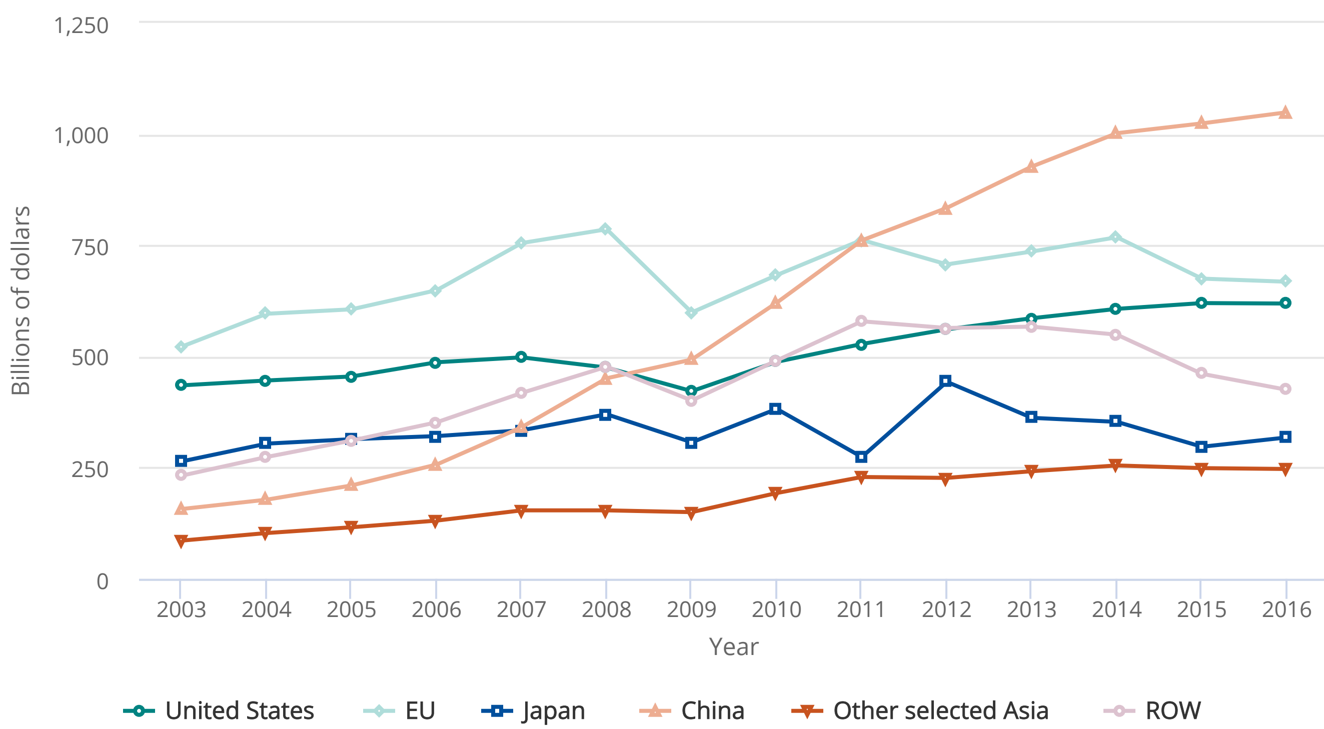
A country's exports of KTI goods and services reflect its ability to compete in the world market. Globally, exports of high-technology products totaled $2.6 trillion in 2016 and are dominated by ICT products. China is the world's largest exporter of high-technology goods (24% of the global share) and 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).

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

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.

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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.

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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.

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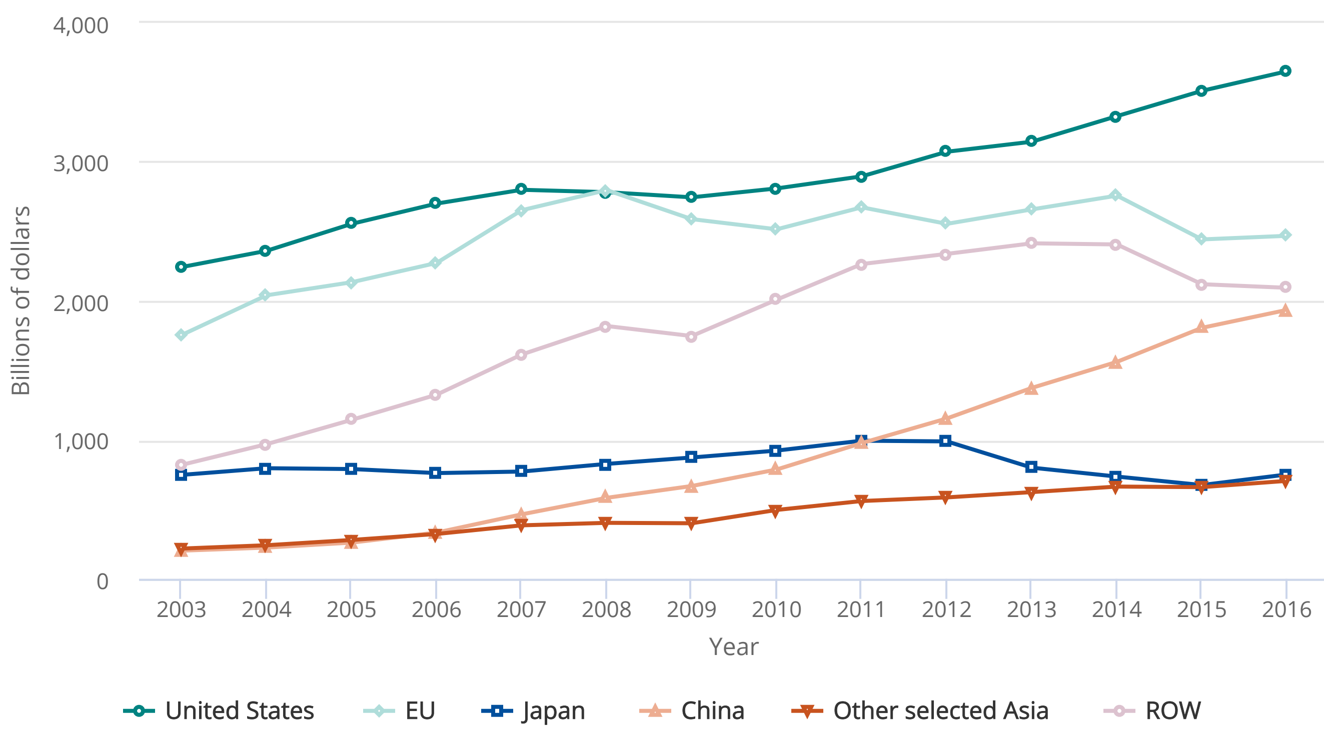
FIGURE O-18

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.

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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

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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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