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Industry Activities

Production and Trade of Knowledge- and Technology-Intensive Industries

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This publication is part of the *Science and Engineering Indicators* suite of reports. *Indicators* is a congressionally mandated report on the state of the U.S. science and engineering enterprise. It is policy relevant and policy neutral. *Indicators* is prepared under the guidance of the National Science Board by the National Center for Science and Engineering Statistics, a federal statistical agency within the National Science Foundation. With the 2020 edition, *Indicators* is changing from a single report to a set of disaggregated and streamlined reports published on a rolling basis. Detailed data tables will continue to be available online.

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Executive Summary

Key takeaways:

- Knowledge- and technology-intensive (KTI) industries—industries that globally invest the largest shares of their output in research and development (R&D)—contributed 11% to both U.S. gross domestic product (GDP) ($2.3 trillion) and global GDP ($9.2 trillion) in 2019.
- Value added generated by domestic KTI industries increased by 2.2% in 2019–20 as industries responded to a surge in demand, even as the overall U.S. GDP declined during the COVID-19 pandemic.
- U.S. KTI production is geographically concentrated, with 15 states accounting for 76% of the total value added generated domestically by KTI industries. California accounts for the largest share (25% in 2020), followed by Texas (8%), Washington (6%), and New York (5%).
- U.S. KTI industries employ disproportionately more workers in science, technology, engineering, and mathematics (STEM) occupations compared to other industries and have high concentrations of foreign-born workers, primarily from India, China, the Philippines, Vietnam, and Mexico.
- The United States and China share the top spot as the world's largest producers of total KTI output (each with a 25% global share of KTI value added in 2019). The United States leads production in KTI services industries, whereas China leads in KTI manufacturing.
- The United States is the world's third-largest exporter of KTI products, behind China and Germany. U.S. KTI exports, however, contain a higher portion of domestic value compared to the KTI exports of China and Germany, indicating a lower reliance on foreign inputs.
- The demand for artificial intelligence (AI)- and biotechnology-related skills, two technologies critical for the rapid response in 2020 to the global pandemic, has grown consistently over the last few years, although it is concentrated within a few states.

R&D activities that advance science and technology (S&T) play a central role in a country's economic growth and competitiveness. KTI industries comprise both manufacturing and services industries with the largest investments in R&D relative to their production. KTI manufacturing industries include air and spacecraft and related machinery; pharmaceuticals; computer, electronic, and optical products; chemicals and chemical products; transportation equipment (excluding aircraft); electrical and other machinery and equipment; and medical and dental instruments. KTI services industries include information technology (IT) and other information services; software publishing; and scientific research and development.

In the United States, the share of GDP produced by KTI industries has been relatively stable at 11% since 2002. However, a shift has occurred in the composition of U.S. KTI output away from manufacturing industries and into services industries. The value added generated by KTI services industries increased much faster than that of manufacturing industries, and as a result, the services share of total KTI value added increased from 29% in 2002 to 47% in 2020. IT and other information services generated the most value added among the KTI services industries, followed by software publishing; these two services industries jointly accounted for 40% of U.S. total KTI value added in 2020.

During the COVID-19 pandemic (2019–20), the value added generated by KTI industries increased even as GDP declined. This increase was led by increases in output of industries that supported aspects of transitioning to remote work and learning and to supplying medical products. During this period, the value added of medical and dental instruments, pharmaceuticals, IT and other information services, software publishing, and computer, electronic, and optical products increased, while manufacturing of chemicals, transportation equipment, and electrical and other machinery and equipment declined.

Although KTI output continues to increase in the United States, it is highly concentrated and specialized geographically. Fifteen states account for 76% of the total value added generated domestically by KTI industries, with California producing the largest share (25% in 2020). KTI industries in Washington account for the largest share of state GDP (24%) compared to other states. KTI manufacturing is concentrated in the Midwest, along the coasts, and in a few states in the South, while KTI services are concentrated along the coasts and a few Southwestern states. For instance, Michigan, Indiana, and Kentucky are the most specialized in motor vehicles manufacturing, while California and Virginia are the most specialized in IT and other information services.

U.S. KTI industries employed 16% of the U.S. science, technology, engineering, and mathematics (STEM) workforce in 2019. Most KTI manufacturing industries employed STEM workers without a bachelor's degree, also known as the skilled technical workforce (STW), at higher proportions compared to STEM workers with a bachelor's degree or above. In contrast, all KTI services industries, as well as pharmaceuticals and computer, electronic, and optical products manufacturers, employed disproportionately more STEM workers with a bachelor's degree or above relative to the STW. Similarly, foreign-born workers make up proportionately more of the STEM workforce in these same industries. Across all KTI industries, foreign-born workers constituted 26% of the STEM workers employed by KTI industries, with India, China, the Philippines, Vietnam, and Mexico being the top 5 countries of birth.

China surpassed the United States to become the world's largest producer of KTI manufacturing output in 2011, and it has been driving the rapid increase of global output for many KTI manufacturing industries over the past decade. China's global share of KTI manufacturing value added has increased from 20% in 2011 to 31% in 2019. Although U.S. KTI manufacturing output continues to increase and the United States continues to account for the largest shares of global value added generated by the air and spacecraft, medical and dental instruments, and pharmaceuticals industries, its share of global KTI manufacturing value added has fluctuated between 19% and 21% since 2011. During this period, the United States has increased its global share of KTI services value added from 30% in 2011 to 37% in 2019. The United States is the largest producer of IT and other information services, which is the largest global KTI industry.

Consistent with its declining global share of KTI manufacturing output, the U.S. share of global KTI exports has fallen over the last decade, and the U.S. trade deficit has widened. In 2019, the United States was the world's third-largest exporter of KTI products, behind China and Germany. The United States, however, has a positive and growing trade balance in KTI services. The decomposition of KTI exports into domestic and foreign value-added content shows that the United States has a lower proportion of foreign value in its KTI exports (averaging 15% in 2002–18) compared to both China (27%) and Germany (24%), indicating a lower reliance on foreign intermediate inputs for its KTI exports. The foreign content share of KTI exports has gradually declined for many countries since 2011, consistent with rising S&T capabilities worldwide. The decline is more pronounced in China (33% in 2004, down to 23% in 2018) and is largely a result of China's efforts to build domestic S&T capacity.

Many KTI industries are either developing or using biotechnology and AI technologies, which are essential to the U.S. life sciences research enterprise and were key to coronavirus research and the development of COVID-19 vaccines. The pharmaceutical industry performs most biotechnology R&D in the United States, and since 2010, the rate of increase in business R&D performance in biotechnology has outpaced that of total domestic R&D. Analysis of the geographic distribution of demand for AI- and biotechnology-related talent shows an increasing demand for both skill sets over the last few years, which accelerated during the COVID-19 pandemic. The demand for AI- and biotechnology-related skills is mainly concentrated in a few states in the West and Northeast. Regional analysis of venture capital data for the U.S. AI and biotechnology sectors shows that venture capital financing is also highly concentrated in the West and Northeast. The dominance of the Northeast and West across these measures is consistent with these regions producing the most KTI output.

Limited internationally comparable data on biotechnology show that the United States performs the most R&D on biotechnology, patents the most biotechnology products, and attracts the most venture capital investment. However, China has recently committed resources to support research and commercialization of biotechnology and has an increasing role in biotechnology patenting and venture capital. Similar to biotechnology, the United States and China are investing heavily in the research and commercialization of AI. Both countries have AI initiatives to increase public funding of AI R&D, develop and improve the skills necessary at the workplace to utilize AI effectively, and promote collaboration between the private sector, universities, and government.

Introduction

Knowledge- and technology-intensive (KTI) industries are the predominant force behind our nation's research and development (R&D) enterprise. These industries produce innovative products and technologies that support economic growth and are essential to address diverse societal challenges, including health, the environment, and national defense. From an economic standpoint, they constitute a modest but critical component of the national gross domestic product (GDP) and employ a sizable fraction of the U.S. science, technology, engineering, and mathematics (STEM) workforce.

This report defines KTI industries as those with the highest R&D intensities based on a taxonomy of economic activities developed by the Organisation for Economic Co-operation and Development (OECD).[1] This definition captures industries with the largest investments in R&D relative to their production. They consist of nine manufacturing industries—chemicals and chemical products; pharmaceuticals; computer, electronic, and optical products; electrical equipment; other machinery and equipment; motor vehicles, trailers, and semi-trailers; air and spacecraft and related machinery; railroad, military vehicles and other transport equipment; medical and dental instruments—and three services industries—information technology (IT) and other information services; software publishing; and scientific research and development.[2]

This report presents analyses on three areas related to KTI industries: production, trade, and enabling technologies. The first section analyzes domestic KTI production and comparative country data on global KTI production. It also presents new analysis on the composition of U.S. KTI employment by STEM workforce categories and the geographic distribution of U.S. KTI production. The second section analyzes global trends in KTI exports, primarily focusing on the foreign value-added content of exports as an indicator of a KTI industry's reliance on foreign intermediate inputs. The third section analyzes data on artificial intelligence (AI) and biotechnology, two important technology areas that many KTI industries are either developing or using and that were critical in the response to the COVID-19 pandemic.

Other aspects relevant to KTI industries are covered in other *Science and Engineering Indicators 2022* reports, including composition and employment trends of the STEM workforce ("[2022] The STEM Labor Force of Today: Scientists, Engineers, and Skilled Technical Workers"), business R&D performance and funding (forthcoming "[2022] Research and Development: U.S. Trends and International Comparisons"), and industry patenting and innovation activities ("[2022] Invention, Knowledge Transfer, and Innovation"). Together, these complementary reports provide a broad picture of the state of knowledge and technology creation, transfer, and adoption in the United States within a global context.

Production Patterns and Trends of Knowledge- and Technology-Intensive Industries

In this report, the featured measure of production for KTI industries is value added in current dollars (not adjusted for inflation). Value added is a net measure of output; it is the difference between the value of goods and services produced by an industry (gross output) and the total cost of intermediate inputs that were used in production, including energy, materials, and services purchased from other businesses. For production activities that take place within a country's geographic borders, industry value added measures the contribution from each industry to overall GDP.

The U.S. data on value added by industry presented in the report are from the Industry and Regional Economic Accounts of the U.S. Bureau of Economic Analysis (BEA). The source for data for KTI employment is the U.S. Census Bureau's 2019 American Community Survey (ACS).[3] International data on value added of KTI industries are drawn from the Comparative Industry Service, a proprietary database from IHS Markit. A detailed description of these data sources is provided in the **Technical Appendix**.

KTI Industries in the United States

KTI industries perform and fund more than half of U.S. R&D (see *Indicators 2020* report, "[2020] Research and Development: U.S. Trends and International Comparisons"). Much of the productivity growth in the United States since the late 1990s is attributable to three of the KTI industries: computer and electronic products, software publishing, and IT services (Nordhaus 2005; Baily and Montalbano 2016). The analysis in this report shows that, compared to other industries, U.S. KTI production has shown resilience to economic downturns (although that varies by disaggregated industries), including the downturn that resulted from the unfolding global COVID-19 pandemic beginning in 2020.

Along with the analysis of overall production trends, this section presents new analysis on the distribution of KTI production across the nation and the composition of KTI employment by STEM workforce categories. Specifically, the regional analysis examines the geographic distribution of U.S. KTI production, the contribution of KTI industries to states' economies, and the regional specialization of KTI production. Even with globalization, geography remains important because competitive advantages often arise from concentrations of highly specialized skills and knowledge, access to institutions, specialized incentives, and other advantages of productivity and innovation that are difficult to access from a distance (Porter 2000).

The analysis on the composition of the KTI employment by STEM workforce categories focuses on underrepresentation of women, Blacks or African Americans, Hispanics or Latinos, and American Indians or Alaska Natives, and the concentration of foreign-born talent. Underrepresentation signals a lack of diversity in the workplace and can negatively impact productivity, innovation, and entrepreneurship (Hsieh et al. 2019; Bell et al. 2019; Flabbi et al. 2019). Because foreign-born workers are proportionately greater in the STEM occupations compared to the general population, immigration policies can affect the flow of this critical source of science and engineering (S&E) skills and knowledge (Kerr and Kerr 2020).

Trends in Value Added of KTI Industries

KTI industries generated nearly $2.4 trillion in value added in 2020 and accounted for over 11% of domestic GDP (**Table KTI-1**). The three largest KTI industries in the United States are IT and other information services; computer, electronic, and optical products; and software publishing. Jointly, they accounted for more than half of the total value added generated by U.S. KTI industries in 2020.

KTI manufacturing industries accounted for 53% of total U.S. KTI value added in 2020, while service industries accounted for the remaining 47% (**Table KTI-1**). Computer, electronic, and optical products; chemicals and chemical products; and pharmaceuticals led production among the KTI manufacturing industries, jointly accounting for 30% of the total value added generated by U.S. KTI industries in 2020. IT and other information services led production among the KTI services industries, followed by software publishing. These two services industries jointly accounted for 40% of U.S. total KTI value added. In addition to its concentration in a few industries, U.S. KTI production is highly concentrated and specialized geographically. (See sidebar **Geography of KTI Production in the United States**.)

Table KTI-1

U.S. KTI industries, by value added and share of GDP: 2019 and 2020

(Billions of dollars and percent)

Industry	ISIC, Rev.4, industry code	2019			2020		
		Value added ($billions)	Share of all KTI industries (%)	Share of GDP (%)	Value added ($billions)	Share of all KTI industries (%)	Share of GDP (%)
GDP		21,372.6		100.0	20,893.7		100.0
All KTI industries		2,336.2	100	10.9	2,387.0	100.0	11.4
Manufacturing		1,301.7	55.7	6.1	1,272.8	53.3	6.1
Chemicals and chemical products	20	208.6	8.9	1.0	199.5	8.4	1.0
Pharmaceuticals	21	182.4	7.8	0.9	195.1	8.2	0.9
Computer, electronic, and optical products	26	310.1	13.3	1.5	319.6	13.4	1.5
Electrical equipment	27	65.0	2.8	0.3	63.6	2.7	0.3
Machinery and equipment nec	28	167.0	7.1	0.8	156.9	6.6	0.8
Motor vehicles, trailers, and semi-trailers	29	149.4	6.4	0.7	145.9	6.1	0.7
Air and spacecraft and related machinery	303	142.3	6.1	0.7	108.1	4.5	0.5
Railroad, military vehicles, and transport nec	302, 304, and 309	11.3	0.5	0.1	11.6	0.5	0.1
Medical and dental instruments	325	65.7	2.8	0.3	72.4	3.0	0.3
Services		1,034.5	44.3	4.8	1,114.2	46.7	5.3
IT and other information services	62 - 63	655.8	28.1	3.1	684.9	28.7	3.3
Software publishing	582	239.3	10.2	1.1	273.0	11.4	1.3
Scientific research and development	72	139.3	6.0	0.7	156.3	6.5	0.7

GDP = gross domestic product; ISIC, Rev.4 = International Standard Industrial Classification, Revision 4; IT = information technology; KTI = knowledge and technology intensive; nec = not elsewhere classified.

Note(s):
Value added is a net measure of output; it is the difference between the value of goods and services produced by an industry (gross output) and the total cost of intermediate inputs that were used in production, including energy, materials, and services purchased from other businesses. *Industry value added* is a measure of an industry's contribution to overall GDP. KTI industries include high R&D intensive and medium-high R&D intensive industries based on a classification by the Organisation for Economic Co-operation and Development. The data have been crosswalked to the ISIC, Rev.4, classification. See the Technical Appendix for the crosswalking method and Table SKTI-1 for historical data on these industries.

Source(s):
U.S. Bureau of Economic Analysis, Value Added by Industry, accessed 5 October 2021.

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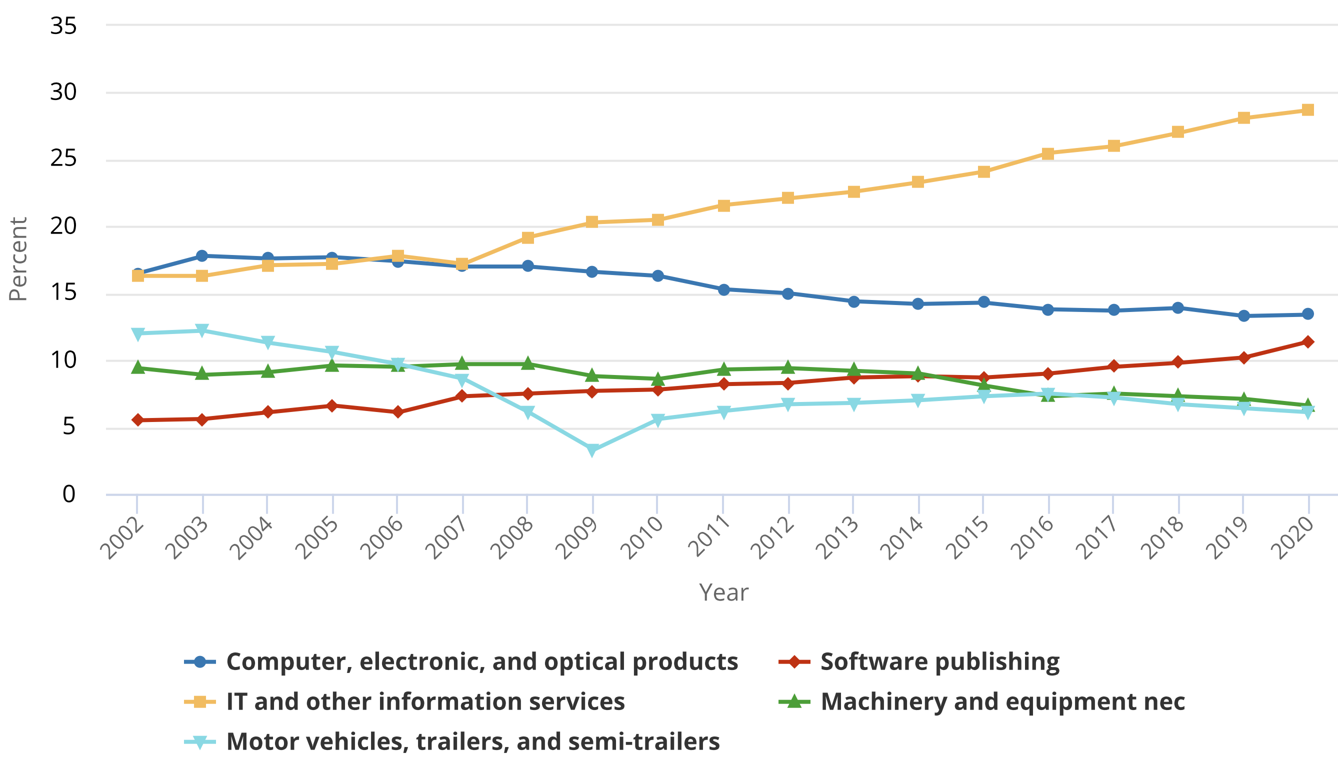
The composition of U.S. KTI production has notably changed since the early 2000s as the value added of KTI services industries has increased much faster than that of manufacturing industries, resulting in the services share of KTI value added increasing from 29% in 2002 to 47% in 2020 (Table SKTI-1). From 2002 to 2020, the share of total KTI value added for IT and other information services—the largest KTI service industry and the largest KTI industry overall—increased by more than 12 percentage points (**Figure KTI-1**). The share of total KTI value added for software publishing also increased by 6 percentage points. A major driver of the increase in software publishing has been the rise in U.S. business investment in software, which nearly tripled from 2002 to 2020 (from $152.5 billion to $453.4 billion) (BEA 2021a).

Figure KTI-1

Industry share of U.S. total KTI value added, by selected industries: 2002–20



IT = information technology; KTI = knowledge and technology intensive; nec = not elsewhere classified.

Note(s):
Value added is a net measure of output; it is the difference between the value of goods and services produced by an industry (gross output) and the total cost of intermediate inputs that were used in production including energy, materials, and services purchased from other businesses. *Industry value added* is a measure of an industry's contribution to overall gross domestic product. KTI industries include high R&D intensive and medium-high R&D intensive industries based on a classification by the Organisation for Economic Co-operation and Development. The data have been crosswalked to the International Standard Industrial Classification, Revision 4. See the Technical Appendix for the crosswalking method and Table SKTI-1 for historical data on these industries.

Source(s):
U.S. Bureau of Economic Analysis, Value Added by Industry, accessed 5 October 2021.

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In contrast, the manufacturing share of total KTI value added declined from 71% in 2002 to 53% in 2020. The share of total KTI value added for computer, electronic, and optical products—the largest KTI manufacturing industry—declined by more than 3 percentage points during this period. Other notable declines include a 6 percentage points drop in the share of motor vehicles manufacturing and a drop of 3 percentage points in other machinery and equipment manufacturing.

SIDEBAR

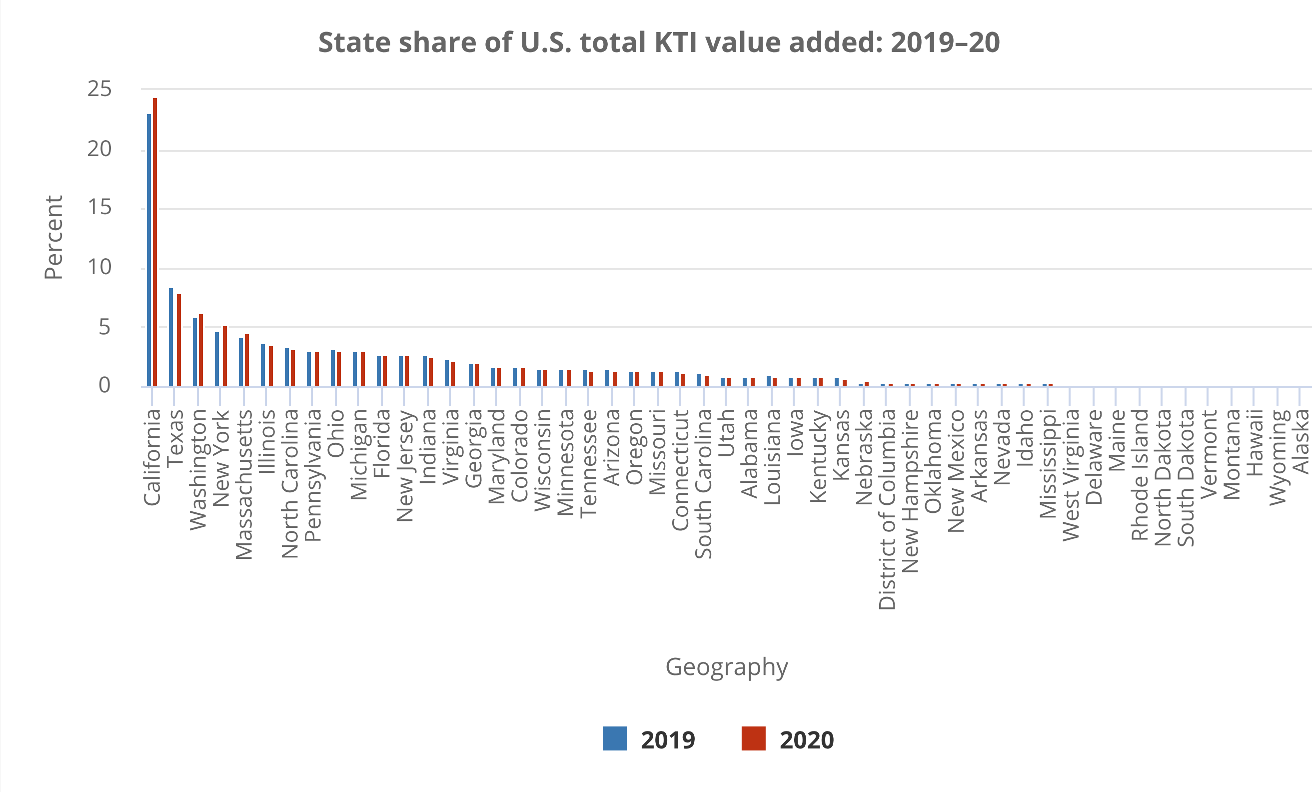
Geography of KTI Production in the United States

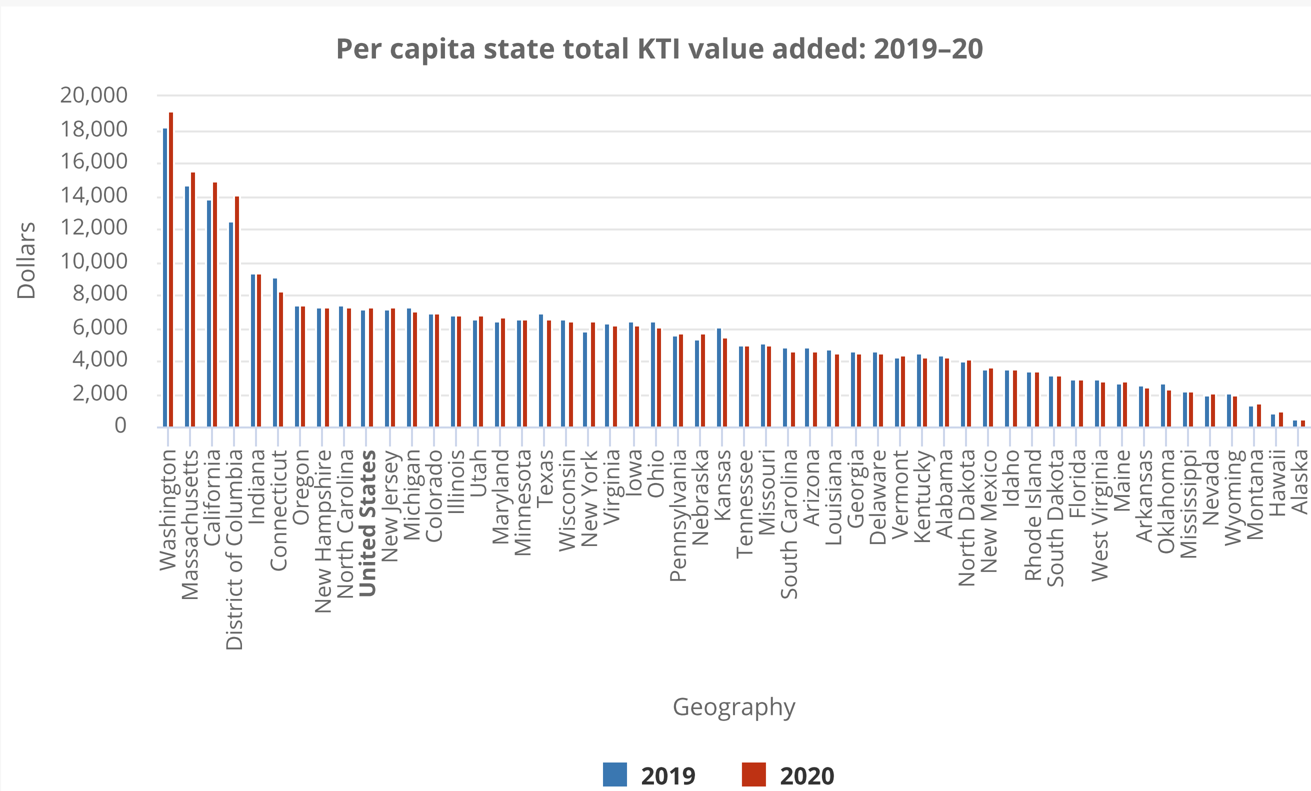
This report presents regional analysis on knowledge- and technology-intensive (KTI) production in the United States. It provides insights on the geographic distribution of U.S. KTI production, the contribution of KTI industries to states' economies, and the regional specialization of KTI production.

KTI production in the United States is concentrated in a few states. By far, California accounted for the largest share of U.S. total KTI value added (25%) in 2020 (**Figure KTI-A**). The states with the next largest shares were Texas (8%), Washington (6%), and New York (5%). Massachusetts, Illinois, North Carolina, Pennsylvania, Ohio, Michigan, Florida, New Jersey, Indiana, Virginia, and Georgia each had shares of the U.S. total KTI value added between 2% and 4%. These top 15 states jointly accounted for 76% of the total value added generated by U.S. KTI industries in 2020.

Figure KTI-A

State share of U.S. total KTI value added and per capita state total KTI value added: 2019–20





KTI = knowledge and technology intensive; nec = not elsewhere classified.

Note(s):
Value added is a net measure of output; it is the difference between the value of goods and services produced by an industry (gross output) and the total cost of intermediate inputs that were used in production including energy, materials, and services purchased from other businesses. *Industry value added* is a measure of an industry's contribution to overall gross domestic product. KTI industries include high R&D intensive and medium-high R&D intensive industries based on a classification by the Organisation for Economic Co-operation and Development. High R&D intensive industries include air and spacecraft and related machinery; pharmaceuticals; computer, electronic, and optical products; scientific research and development; and software publishing. Medium-high R&D intensive industries include motor vehicles, trailers, and semi-trailers; medical and dental instruments; machinery and equipment nec; chemicals and chemical products; electrical equipment; railroad, military vehicles, and transport nec; and information technology and other information services. The underlying industry data are based on the International Standard Industrial Classification, Revision 4.

Source(s):
U.S. Bureau of Economic Analysis, Annual Gross Domestic Product (GDP) by State, special tabulations, October 2021.

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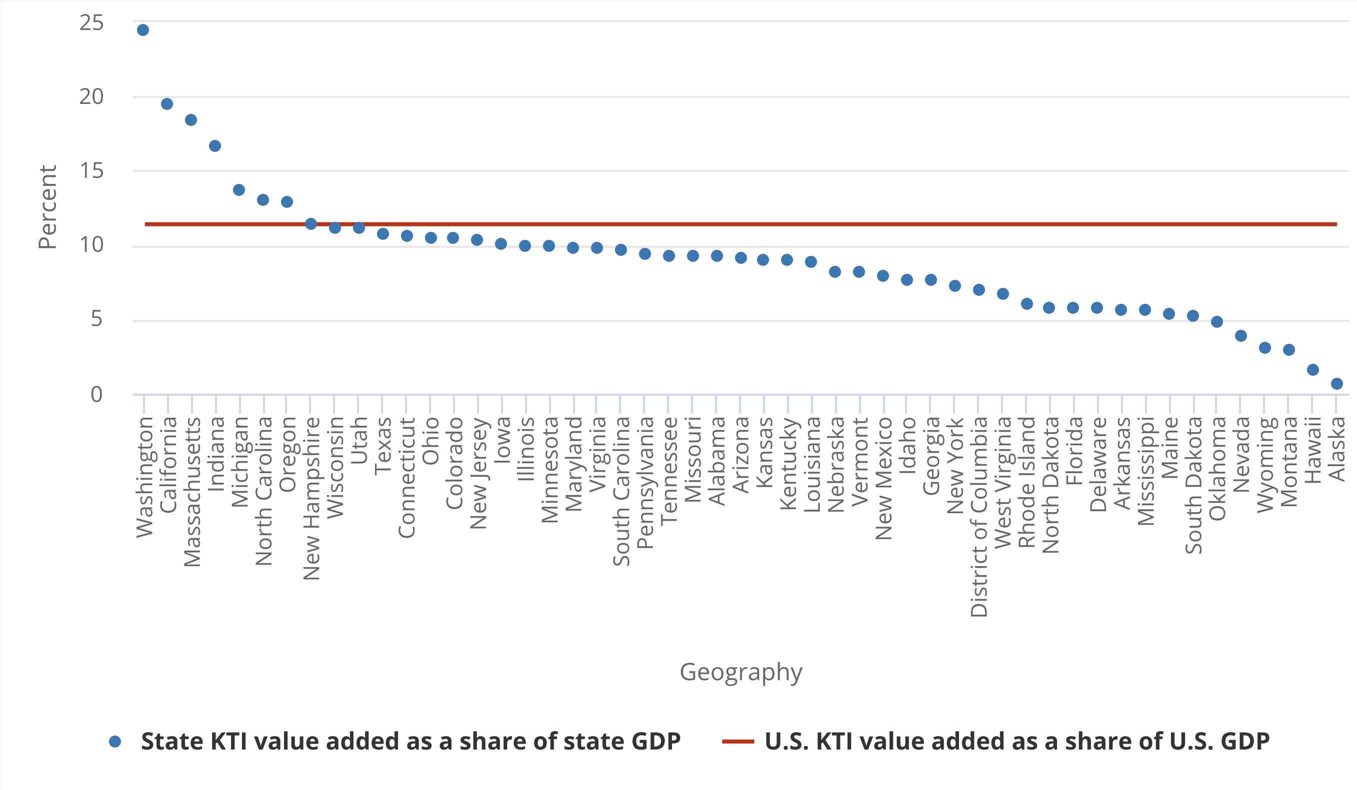
These rankings change moderately when looking at KTI value added per capita. Washington, Massachusetts, and California were the top 3 states in per capita terms, each with nearly $15,000 or more per capita total KTI value added in 2020 (**Figure KTI-A**). The District of Columbia followed with a per capita value of more than $14,000. To put this into context, the average per capita KTI value added for the United States was $7,245 in 2020. Other states with per capita values higher than the national average were Indiana, Connecticut, Oregon, New Hampshire, and North Carolina.

KTI production as a share of the states' economies varies widely across states. On average, U.S. KTI production accounted for about 11% of gross domestic product (GDP) in 2020. The KTI share of state GDP varied from over 24% in Washington to less than 1% in Alaska (**Figure KTI-B**). California, Massachusetts, Indiana, Michigan, North Carolina, and Oregon also had KTI industries that make up larger than average shares of the state's economy (13%–19%).

Figure KTI-B

KTI value added as a share of U.S. and state GDP: 2020



GDP = gross domestic product; KTI = knowledge and technology intensive; nec = not elsewhere classified.

Note(s):
Value added is a net measure of output; it is the difference between the value of goods and services produced by an industry (gross output) and the total cost of intermediate inputs that were used in production including energy, materials, and services purchased from other businesses. *Industry value added* is a measure of an industry's contribution to overall GDP. KTI industries include high R&D intensive and medium-high R&D intensive industries based on a classification by the Organisation for Economic Co-operation and Development. High R&D intensive industries include air and spacecraft and related machinery; pharmaceuticals; computer, electronic, and optical products; scientific research and development; and software publishing. Medium-high R&D intensive industries include motor vehicles, trailers, and semi-trailers; medical and dental instruments; machinery and equipment not elsewhere classified nec; chemicals and chemical products; electrical equipment; railroad, military vehicles, and transport nec; and information technology and other information services. The underlying industry data are based on the International Standard Industrial Classification, Revision 4.

Source(s):
U.S. Bureau of Economic Analysis, Annual Gross Domestic Product (GDP) by State, special tabulations, October 2021.

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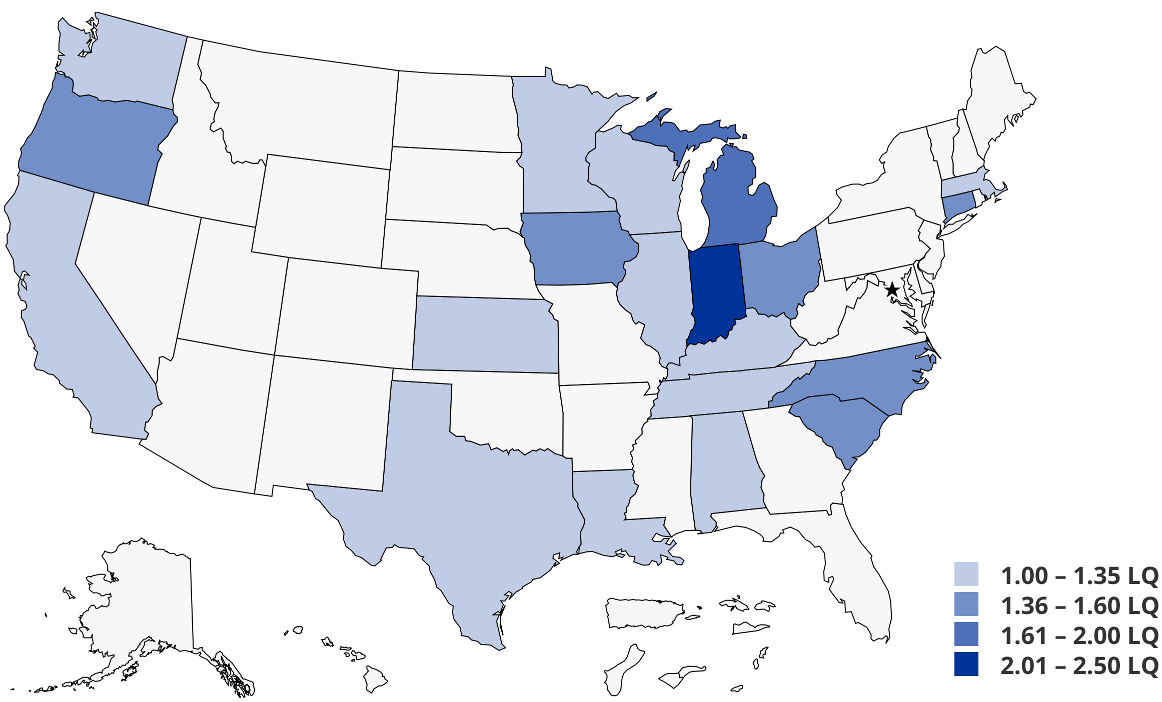
Industry specialization of KTI production also varies by state. A way to quantify industry specialization is by computing location quotients (LQ),* a statistic that compares an industry's share of a region's GDP with the corresponding industry's share of national GDP (Carroll, Reid, and Smith 2008; Chiang 2009; Crawley, Beynon, and Munday 2013). The LQ analysis shows that KTI manufacturing is concentrated in the Midwest, along the coasts, and a few states in the South (**Figure KTI-C**). KTI services are primarily concentrated along the coasts and a few Southwestern states (Utah, Colorado, and New Mexico).

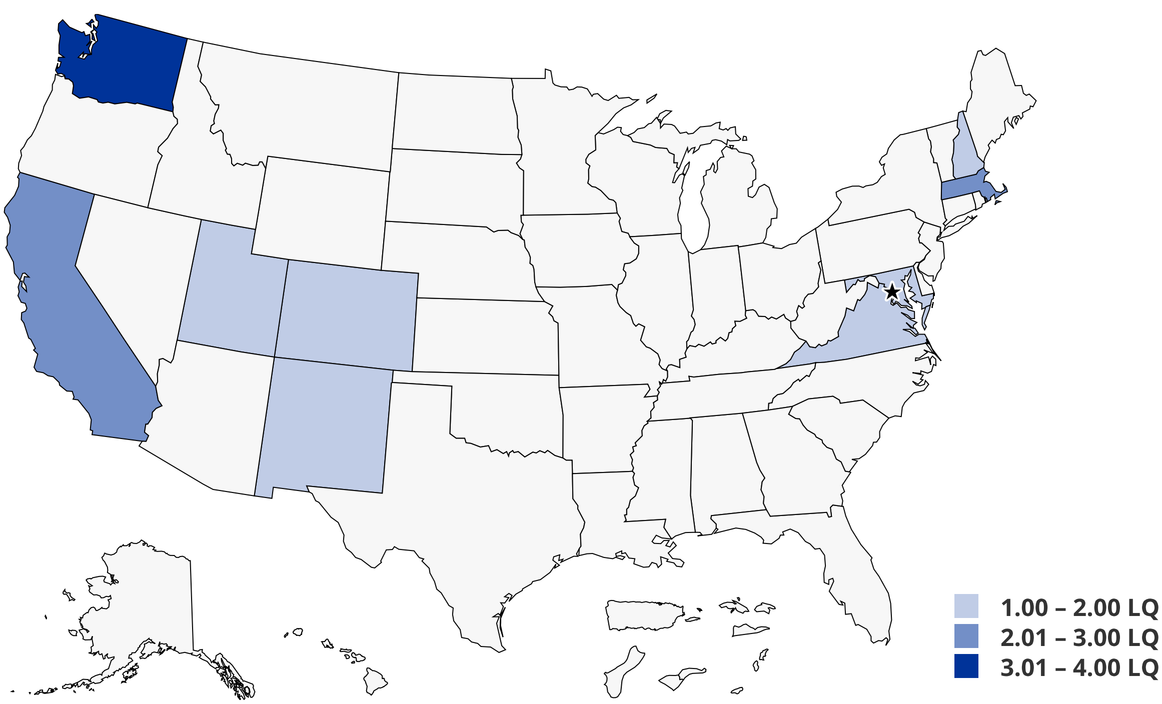
Figure KTI-C

Specialization in KTI industry production, by state: 2020

KTI manufacturing, 2020



KTI services, 2020



KTI = knowledge and technology intensive; nec = not elsewhere classified.

Note(s):
Location quotient (LQ) is the ratio of a KTI industry's share of a state's gross domestic product (GDP) to the corresponding industry's share of national GDP. Only states with LQ > 1.00 are shown. KTI industries include high R&D intensive and medium-high R&D intensive industries based on a classification by the Organisation for Economic Co-operation and Development. KTI manufacturing industries are chemicals and chemical products; pharmaceuticals; computer, electronic, and optical products; electrical equipment; machinery and equipment nec; motor vehicles, trailers, and semi-trailers; air and spacecraft and related machinery; railroad, military vehicles, and transport nec; and medical and dental instruments. KTI services industries are information technology and other information services; software publishing, and scientific research and development. The underlying industry data are based on the International Standard Industrial Classification, Revision 4. Calculations are performed on unrounded numbers.

Source(s):
U.S. Bureau of Economic Analysis, Annual Gross Domestic Product (GDP) by State, special tabulations, October 2021.

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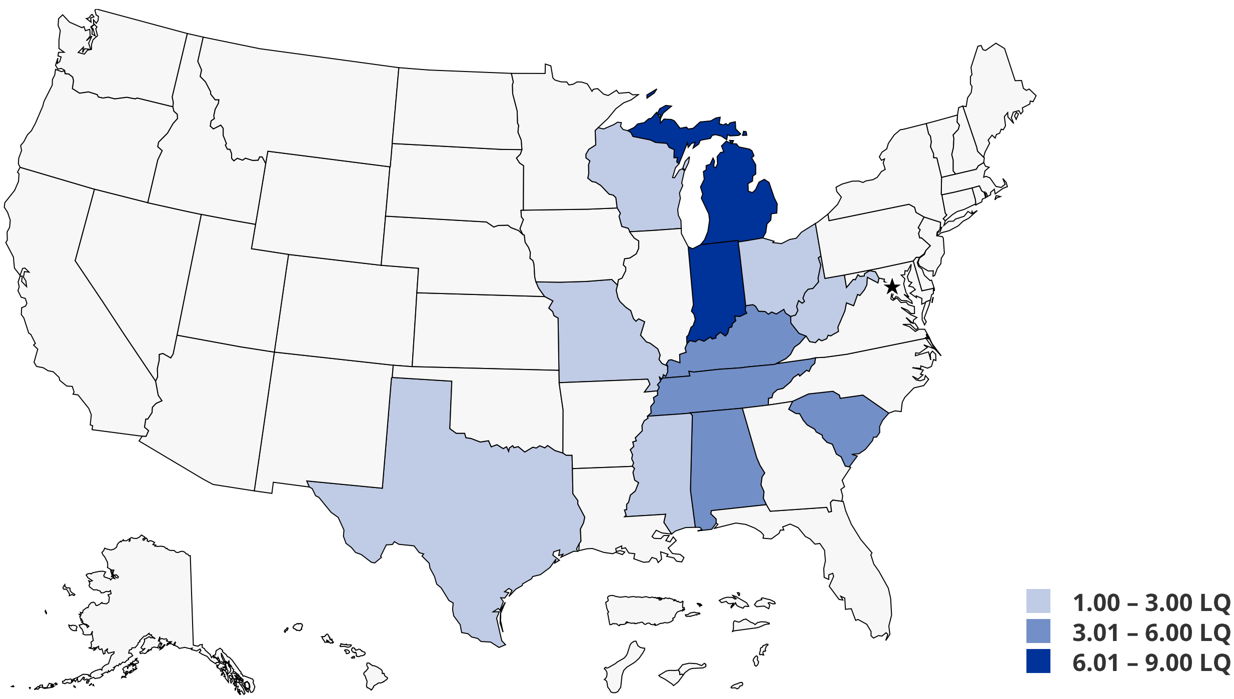
The LQ analysis for two detailed KTI industries shows that states on the coasts are relatively more specialized in production of information technology (IT) and other information services, whereas states in the Midwest are more specialized in the production of motor vehicles (**Figure KTI-D**). In particular, California and Virginia are the two states most specialized in IT and other information services as their value-added-to-GDP ratio was more than twice the national average in 2020. Michigan, Indiana, and Kentucky are the most specialized in motor vehicles manufacturing with valued-added-to-GDP ratios more than five times the national average. Other states with high specialization in motor vehicles manufacturing are Tennessee, Alabama, South Carolina, Mississippi, and Ohio.

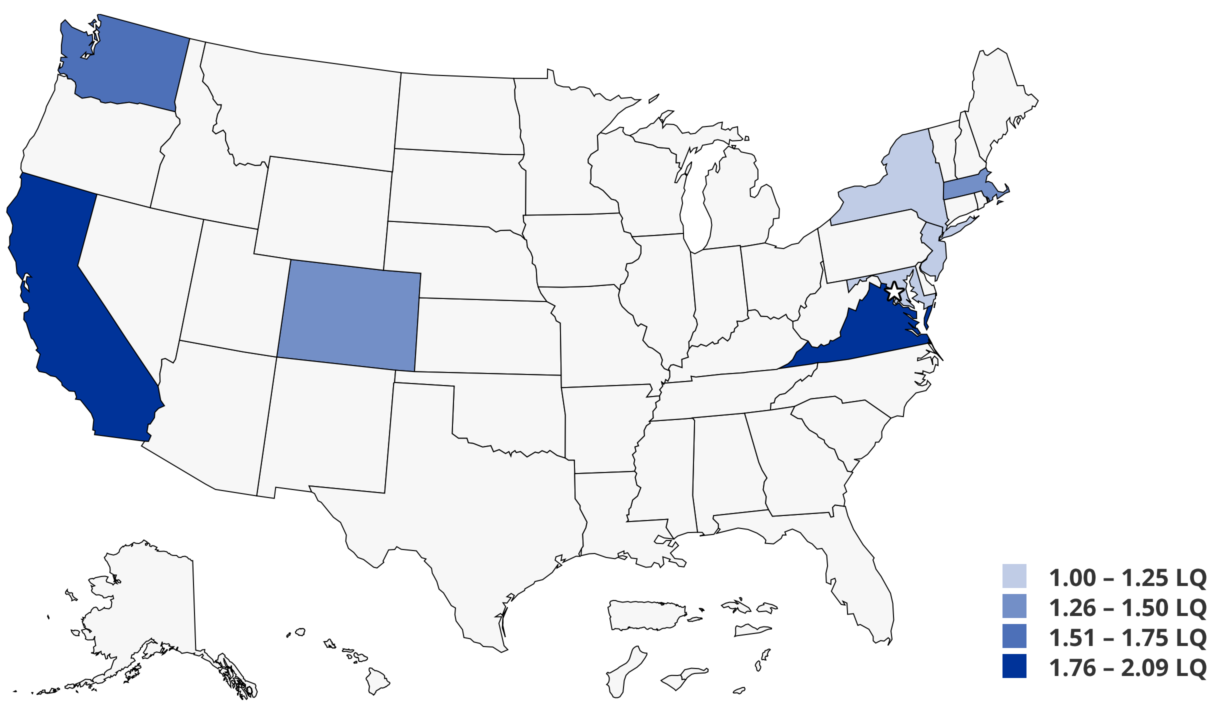
Figure KTI-D

Specialization in production for two selected industries, by state: 2020

Motor vehicles, trailers, and semi-trailers



IT and other information services



IT = information technology; KTI = knowledge and technology intensive.

Note(s):
Location quotient (LQ) is the ratio of a KTI industry's share of a state's gross domestic product (GDP) to the corresponding industry's share of national GDP. Only states with LQ > 1.00 are shown. KTI industries include high R&D intensive and medium-high R&D intensive industries based on a classification by the Organisation for Economic Co-operation and Development. The industry data are based on the International Standard Industrial Classification, Revision 4. Calculations are performed on unrounded numbers.

Source(s):
U.S. Bureau of Economic Analysis, Annual Gross Domestic Product (GDP) by State, special tabulations, October 2021.

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* An LQ of 1.0 in a given industry means that the region and the nation are equally specialized in the industry. An LQ greater than 1.0 in an industry means that the region is relatively more specialized than the nation in that industry.

The rate of increase in KTI value added has outpaced that of current dollar GDP for more than a decade (**Table KTI-2**). From 2005 to 2010—a period that includes the Great Recession—KTI value added increased on average 4.3%, moderately faster than the 2.9% average increase in GDP. The average annual increase in KTI value added was a full percentage point higher than the rate of GDP increase (4.9%, compared to 3.9%) from 2010 to 2015. Since 2015, KTI value added has increased faster than GDP each year, driven primarily by the KTI services industries with annual increases ranging from 7.3% to 11.1%. KTI value added continued to increase through 2020, albeit at a lower rate, despite the COVID-19 pandemic's effect on the economy.

Table KTI-2

Annual rates of change in U.S. KTI value added and GDP: 2002–20

(Percent)

Industry	ISIC, Rev.4, industry code	Longer-term trends			Recent years				
		2002–05	2005–10	2010–15	2015–16	2016–17	2017–18	2018–19	2019–20
GDP		6.1	2.9	3.9	2.7	4.2	5.4	4.1	-2.2
All KTI industries		4.5	4.3	4.9	4.1	5.0	7.3	5.7	2.2
Manufacturing		3.8	3.0	3.3	1.8	3.5	4.7	2.6	-2.2
Chemicals and chemical products	20	2.6	7.6	1.5	7.0	1.1	4.7	-0.8	-4.3
Pharmaceuticals	21	2.1	4.8	2.4	7.3	2.3	2.1	10.2	7.0
Computer, electronic, and optical products	26	6.9	2.6	2.2	0.3	4.4	8.9	1.0	3.1
Electrical equipment	27	-0.4	3.3	4.6	-8.2	4.0	7.1	-0.1	-2.2
Machinery and equipment nec	28	5.0	2.1	3.6	-5.7	6.7	5.2	3.5	-6.1
Motor vehicles, trailers, and semi-trailers	29	0.2	-8.1	10.5	6.2	2.0	-0.6	0.8	-2.3
Air and spacecraft and related machinery	303	7.2	6.9	4.6	-2.3	6.3	4.4	5.5	-24.0
Railroad, military vehicles, and transport nec	302, 304, and 309	8.2	3.7	2.3	6.6	-16.6	-1.2	-4.1	3.4
Medical and dental instruments	325	4.2	7.6	-0.7	6.8	4.8	4.4	2.2	10.1
Services		6.3	7.1	7.6	7.6	7.3	11.1	9.9	7.7
IT and other information services	62 - 63	6.5	8.0	8.4	10.0	7.0	11.4	9.9	4.4
Software publishing	582	11.3	7.8	7.3	7.4	10.7	10.7	10.9	14.1
Scientific research and development	72	1.4	3.6	5.3	-1.7	2.8	10.1	8.4	12.1

GDP = gross domestic product; ISIC, Rev.4 = International Standard Industrial Classification, Revision 4; IT = information technology; KTI = knowledge and technology intensive; nec = not elsewhere classified.

Note(s):
Value added is a net measure of output; it is the difference between the value of goods and services produced by an industry (gross output) and the total cost of intermediate inputs that were used in production, including energy, materials, and services purchased from other businesses. *Industry value added* is a measure of an industry's contribution to overall GDP. KTI industries include high R&D intensive and medium-high R&D intensive industries based on a classification by the Organisation for Economic Co-operation and Development. The data have been crosswalked to the ISIC, Rev.4, classification. See the Technical Appendix for the crosswalking method and Table SKTI-1 for historical data on these industries. Longer-term trend rates are calculated as compound annual growth rates.

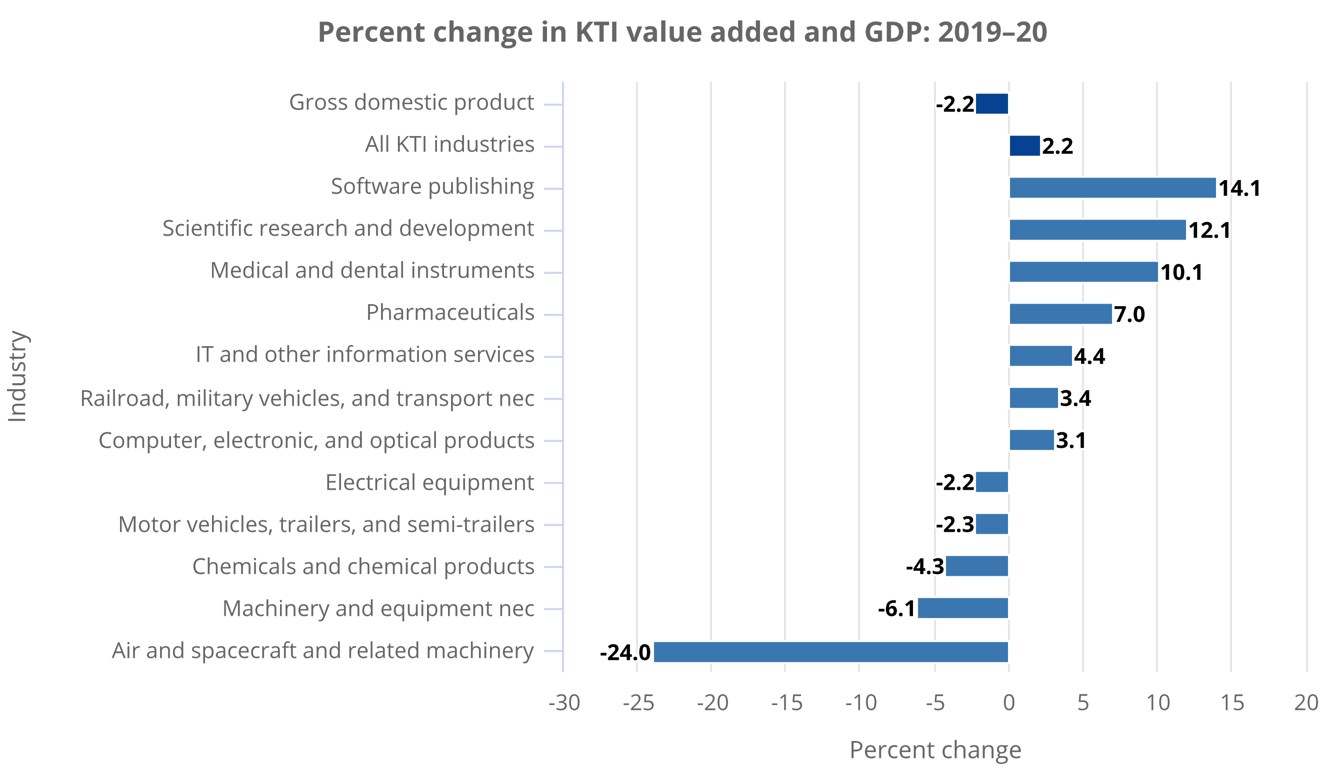
Source(s):
U.S. Bureau of Economic Analysis, Value Added by Industry, accessed 5 October 2021.

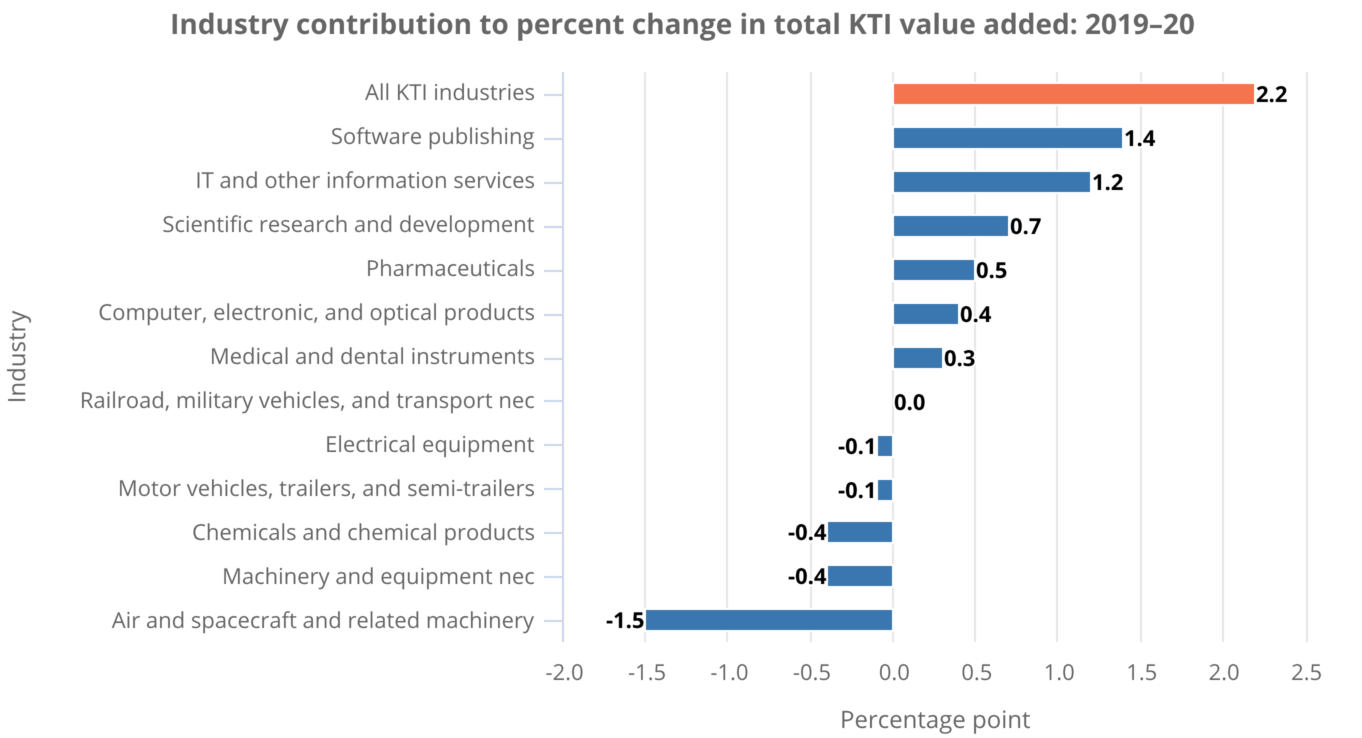
Science and Engineering Indicators

In 2020, even as GDP declined by nearly half a trillion dollars (or 2.2%), KTI value added increased by over $50 billion (or 2.2%) (**Figure KTI-2**; Table SKTI-1).[4] This increase was led by increases in value added generated by information and communications technology (ICT) industries (IT and other information services; software publishing; and computer, electronic, and optical products), scientific research and development, medical and dental instruments, and pharmaceuticals.

Figure KTI-2

Percent change and contribution to percent change in KTI value added: 2019–20





IT = information technology; KTI = knowledge and technology intensive; nec = not elsewhere classified.

Note(s):
Value added is a net measure of output; it is the difference between the value of goods and services produced by an industry (gross output) and the total cost of intermediate inputs that were used in production including energy, materials, and services purchased from other businesses. *Industry value added* is a measure of an industry's contribution to overall gross domestic product. KTI industries include high R&D intensive and medium-high R&D intensive industries based on a classification by the Organisation for Economic Co-operation and Development. The data have been crosswalked to the International Standard Industrial Classification, Revision 4. See the Technical Appendix for the crosswalking method and Table SKTI-1 for historical data on these industries.

Source(s):
U.S. Bureau of Economic Analysis, Value Added by Industry, accessed 5 October 2021.

Science and Engineering Indicators

The single biggest increase was in the value added generated by the software publishing industry, which increased by over 14% (**Figure KTI-2**; **Table KTI-2**). The value added generated by IT and other information services and computer, electronic, and optical products also increased (4% and 3%, respectively); collectively, these industries contributed more than 3 percentage points to the increase in total KTI value added in 2020. ICT industries played a central role in many aspects of the pandemic, including supporting businesses and schools in the transition to remote work and remote learning as well as assisting medical professionals in the digital delivery of healthcare services (Brynjolfsson et al. 2020; Bacher-Hicks, Goodman, and Mulhern 2020; Bokolo 2020).

Other notable increases were in the value added generated by the scientific research and development (12%), medical and dental instruments (10%), and pharmaceuticals (7%) industries. These industries were essential to the production of medicine, medical equipment, and supplies needed to treat the virus and the development of COVID-19 vaccines. They jointly contributed 1.5 percentage points to the increase in total KTI value added as the surge in demand due to the COVID-19 pandemic caused significant shortages in medical supplies (Gereffi 2020; Nagurney, Salarpour, and Dong 2021).[5]

The output of several KTI industries declined from 2019 to 2020, largely as a result of pandemic-induced supply chain disruptions.[6] The value added generated by manufacturing of air and spacecraft, motor vehicles, electrical equipment, other machinery and equipment, and chemicals and chemical products declined (**Figure KTI-2**). Among these industries, the value added generated by the air and spacecraft industry had the largest decline (24%) and subtracted 1.5 percentage points from the increase in total KTI value added.

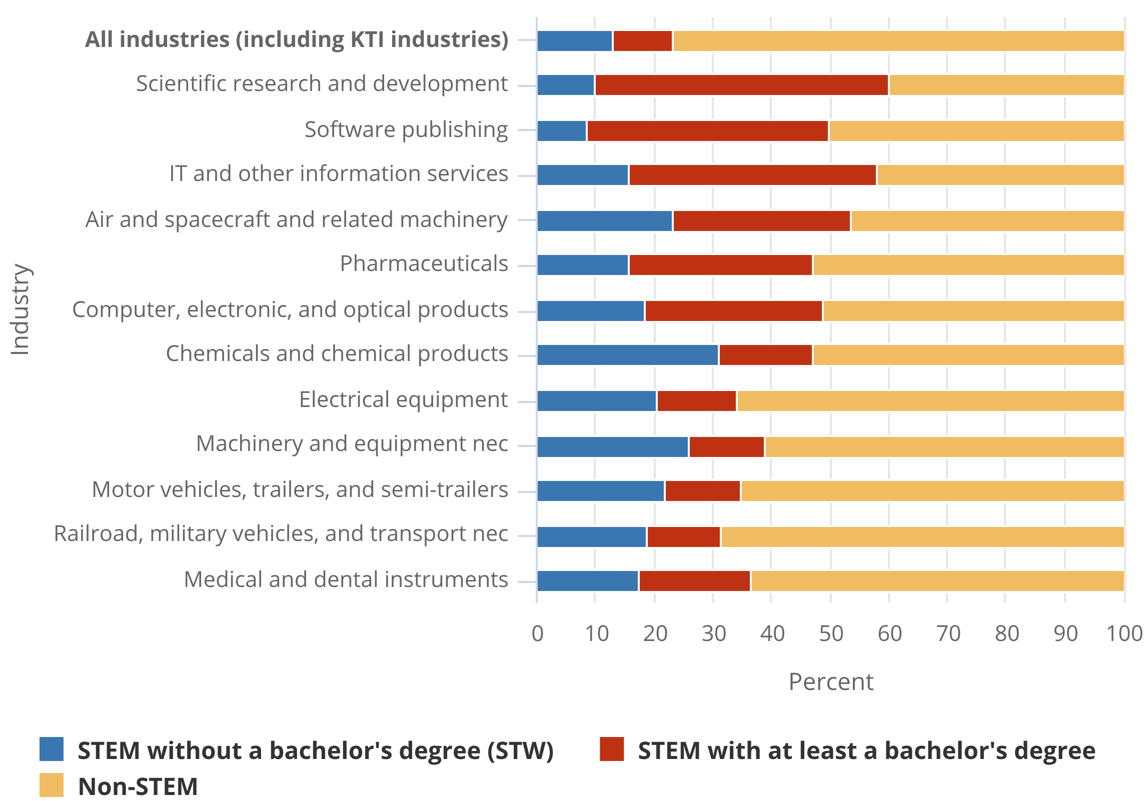
Employment in KTI Industries

KTI industries employed approximately 12 million workers, accounting for 8% of total U.S. employment in 2019 and 16% of the STEM workforce (Table SKTI-2).[7] Among KTI industries, the IT and other information services industry employed the most workers, accounting for 32% of the total KTI workforce. The next three largest industries in terms of employment (motor vehicles; computer, electronic and optical products; and other machinery and equipment manufacturers) jointly employed another 32% of workers in KTI industries.

Compared to all industries, KTI industries employed disproportionately more workers in STEM occupations. At the low end, workers in STEM occupations comprised 35% of those employed by motor vehicle manufacturers. At the high end, they comprised 60% of those employed by the scientific research and development industry (**Figure KTI-3**). In comparison, workers in STEM occupations comprised about a quarter of the U.S. workers across all industries (see *Indicators 2022* report, "[2022] The STEM Labor Force of Today: Scientists, Engineers, and Skilled Technical Workers").

Figure KTI-3

Workers in each KTI industry, by workforce and education: 2019



IT = information services; KTI = knowledge and technology intensive; nec = not elsewhere classified; STEM = science, technology, engineering, and mathematics; STW = skilled technical workforce.

Note(s):
KTI industries include high R&D intensive and medium-high R&D intensive industries based on a classification by the Organisation for Economic Co-operation and Development. Data include workers ages 16–75 and exclude those in military occupations or currently enrolled in primary or secondary school. Values may not add up to 100% because of rounding.

Source(s):
U.S. Census Bureau, American Community Survey (ACS), 2019, Public Use Microdata Sample (PUMS), accessed 12 December 2020.

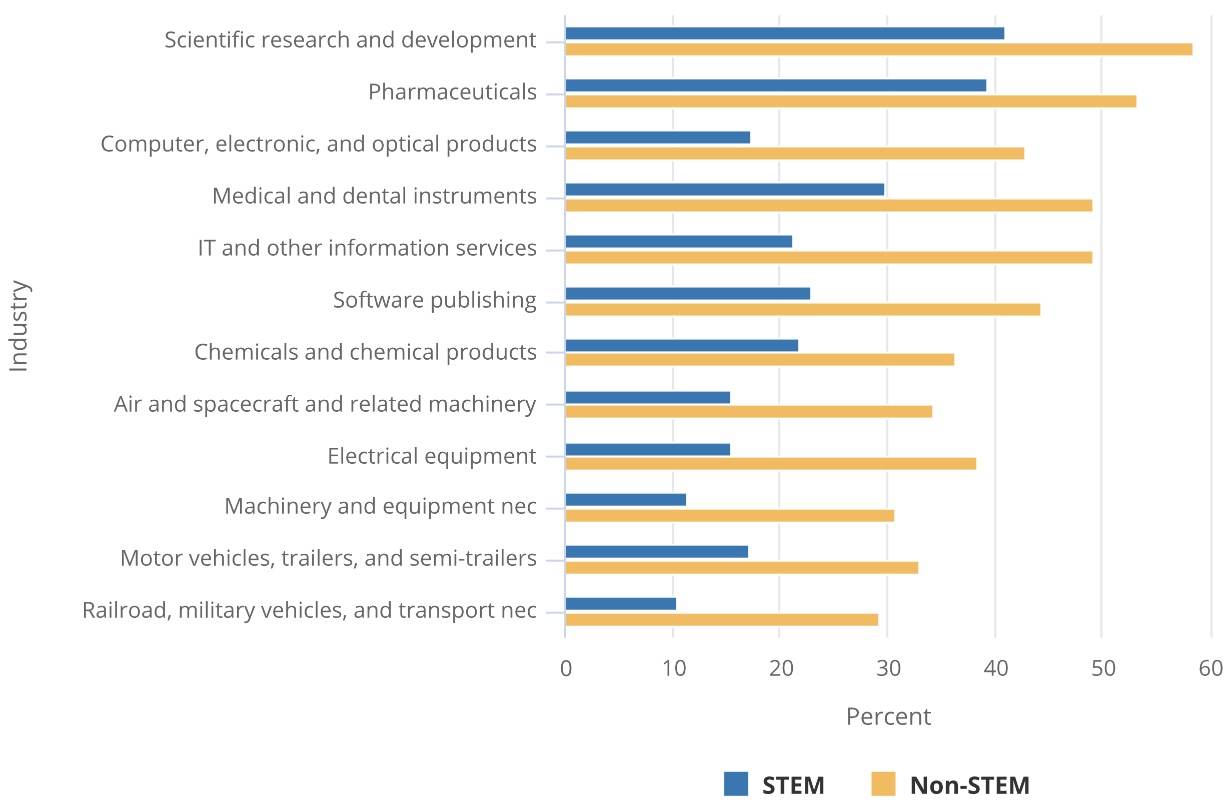
Science and Engineering Indicators

STEM workers without a bachelor's degree—also called the skilled technical workforce (STW)—were more concentrated in KTI manufacturing industries compared to KTI services industries (Table SKTI-2).[8] The STW made up more than half of STEM workers in five of the nine KTI manufacturing industries. The manufacturing industries that have less than half of their STEM workers without a bachelor's degree were air and spacecraft, pharmaceuticals, medical and dental instruments, and computer, electronic, and optical products. More than half of STEM workers in the service KTI industries (scientific research and development, software publishing, and IT and other information services) have at least a bachelor's degree.

There were disproportionately less women in most KTI industries than in the U.S. population in 2019 (Table SKTI-3). However, the proportions of women employed in the pharmaceuticals (47%) and scientific research and development industries (48%) were similar to the resident U.S. population (51%) (NCSES **WMPD 2021**: **Table 1-1**). The proportion of women in the pharmaceuticals and scientific research and development industries falls 7–8 percentage points when analyzing those in STEM occupations only (**Figure KTI-4**). Overrepresentation of women in non-STEM occupations drives the comparatively large proportion of women in these industries.

Figure KTI-4

Women employed in KTI industries, by workforce: 2019



IT = information technology; KTI = knowledge and technology intensive; STEM = science, technology, engineering, and mathematics; nec = not elsewhere classified.

Note(s):
KTI industries include high R&D intensive and medium-high R&D intensive industries based on a classification by the Organisation for Economic Co-operation and Development. Data include workers ages 16–75 and exclude those in military occupations or currently enrolled in primary or secondary school. Percentages may not add up to 100% because of rounding.

Source(s):
U.S. Census Bureau, American Community Survey (ACS), 2019, Public Use Microdata Sample (PUMS), accessed 12 December 2020.

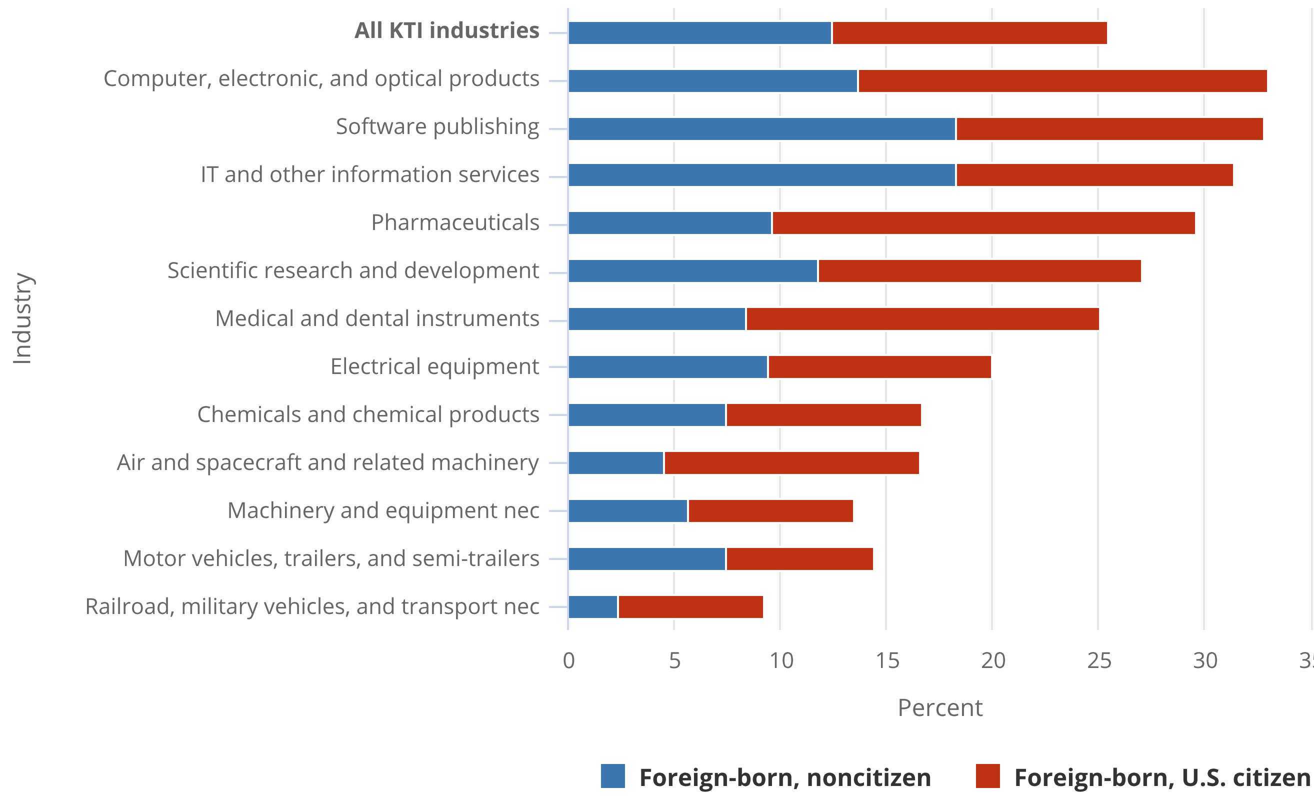
Science and Engineering Indicators

Other underrepresented groups, including Blacks or African Americans, Hispanics or Latinos, and American Indians or Alaska Natives—also known as underrepresented minorities—are also less represented in KTI industries (19%) compared to their representation in the resident U.S. population (32%) (NCSES **WMPD 2021**: **Table 1-2**).[9] The highest proportion of underrepresented minorities employed in KTI are in the motor vehicles (27%), chemicals (26%) and the electrical equipment (24%) industries across all occupations (Table SKTI-3). Among occupations categorized as STEM, underrepresented minorities make up a lower proportion (16%) of workers in KTI industries.

Foreign-born workers are a large proportion of STEM workers across all KTI industries (26%) (**Figure KTI-5**). However, foreign-born workers make up proportionately more than the average in all the service KTI industries (IT and other information services, scientific research and development, and software publishing); pharmaceuticals; and computer, electronic, and optical products. This relationship holds for workers in non-STEM occupations as well, although the prevalence of foreign-born workers in STEM occupations is generally higher than in the non-STEM occupations (Table SKTI-3). In general, KTI industries with the highest concentrations of foreign-born workers are those industries with the highest concentrations of workers with at least a bachelor's degree.

Figure KTI-5

Foreign-born STEM workers in each KTI industry, by citizenship: 2019



IT = information technology; KTI = knowledge and technology intensive; nec = not elsewhere classified; STEM = science, technology, engineering, and mathematics.

Note(s):
KTI industries include high R&D intensive and medium-high R&D intensive industries based on a classification by the Organisation for Economic Co-operation and Development. Data include workers ages 16–75 and exclude those in military occupations or currently enrolled in primary or secondary school.

Source(s):
U.S. Census Bureau, American Community Survey (ACS), 2019, Public Use Microdata Sample (PUMS), accessed 12 December 2020.

Science and Engineering Indicators

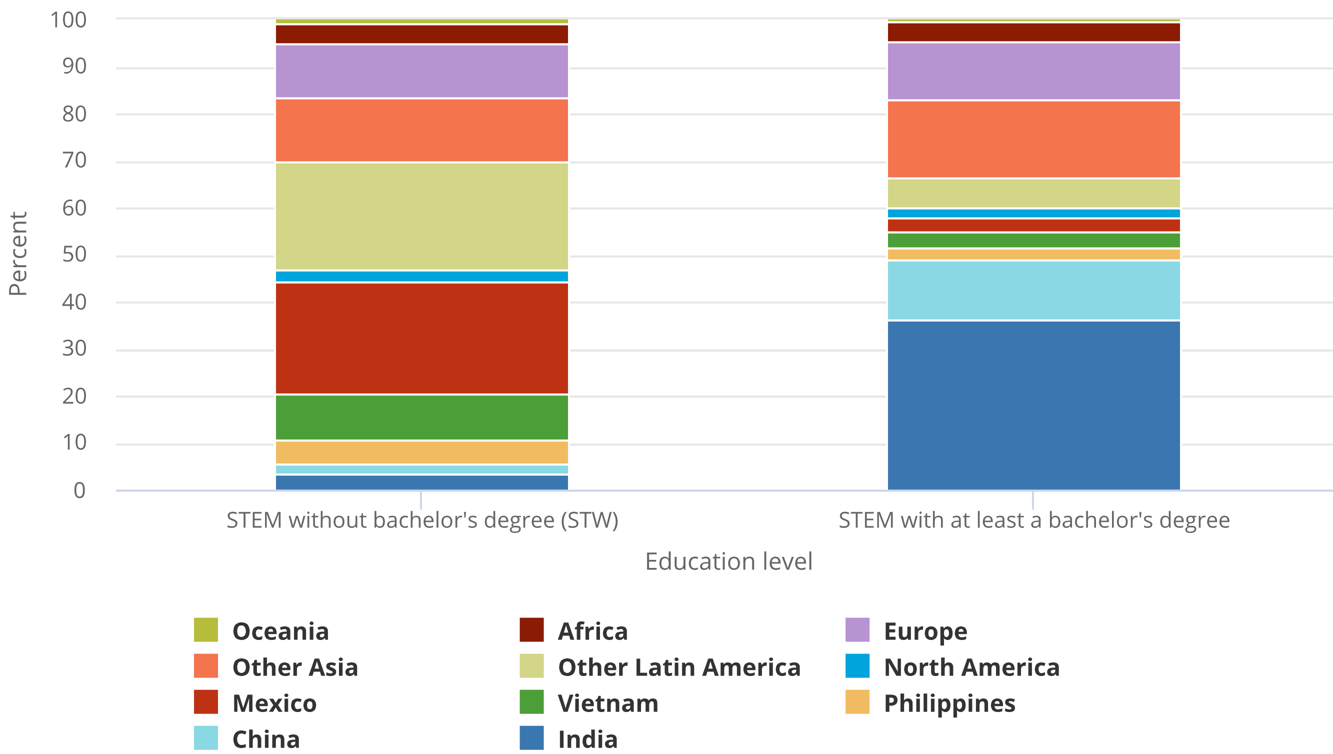
Although most foreign-born workers in KTI industries are U.S. citizens, software publishing and IT and other information services had higher than average rates of noncitizen workers (Table SKTI-3).[10] Among STEM workers in the IT and other information services industry, which is the largest employer among the KTI industries, 31% are foreign born—with 13% being U.S. citizens, and 18% being noncitizens (**Figure KTI-5**). Foreign-born and noncitizen STEM workers in the software publishing industry are similarly distributed.

Most foreign-born workers in KTI industries in the STW are from Mexico and other Latin American countries, whereas China, India, and other Asian countries are the primary birth places of those in STEM occupations with a bachelor's degree or above. In 2019, the top 5 countries of birth for foreign-born workers in all KTI industries were India, China, the Philippines, Vietnam, and Mexico. Almost half of foreign-born STEM workers with a bachelor's degree or above working in

KTI industries were from China and India (**Figure KTI-6**). Another 29% of these workers were from European and other Asian countries. In contrast, almost a quarter of STEM foreign-born workers without a bachelor's degree were from Mexico, with almost another fourth from other Latin American countries. Foreign-born workers from Mexico worked proportionately more in non-STEM occupations within KTI industries as well.

Figure KTI-6

Foreign-born KTI workers in STEM occupations, by country or region of birth and education level: 2019



KTI = knowledge and technology intensive; nec = not elsewhere classified; STEM = science, technology, engineering, and mathematics; STW = skilled technical workforce.

Note(s):
KTI industries include high R&D intensive and medium-high R&D intensive industries based on a classification by the Organisation for Economic Co-operation and Development. High R&D intensive industries include air and spacecraft and related machinery; pharmaceuticals; computer, electronic, and optical products; scientific research and development; and software publishing. Medium-high R&D intensive industries include motor vehicles, trailers, and semi-trailers; medical and dental instruments; machinery and equipment nec; chemicals and chemical products; electrical equipment; railroad, military vehicles, and transport nec; and information technology and other information services. Data include workers ages 16–75 and exclude those in military occupations or currently enrolled in primary or secondary school. Values may not add up to 100% because of rounding. Countries listed are top 5 countries of foreign-born KTI workers.

Source(s):
U.S. Census Bureau, American Community Survey (ACS), 2019, Public Use Microdata Sample (PUMS), accessed 12 December 2020.

Science and Engineering Indicators

KTI Industries in the Global Economy

Globally, KTI industries generated $9.2 trillion in value added in 2019, accounting for almost 12% of global GDP (**Table KTI-3**). KTI manufacturing industries generated 70% of global KTI value added. However, among the individual industries, IT services led production of KTI output (19% of global KTI value added). Computer, electronic, and optical products (14%), other machinery and equipment (13%), motor vehicles (12%), and chemicals and chemical products (11%) followed as the next-largest global KTI industries. These five industries jointly accounted for 68% of global KTI value added in 2019.

Table KTI-3

Global KTI industries, by value added and share of global GDP: 2019

(Billions of dollars and percent)

Industry	ISIC, Rev.4, industry code	Value added ($billions)	Share of global KTI (%)	Share of global GDP (%)
All KTI industries		9,220.0	100.0	11.5
Manufacturing		6,407.5	69.5	8.0
Chemicals and chemical products	20	1,052.9	11.4	1.3
Pharmaceuticals	21	658.0	7.1	0.8
Computer, electronic, and optical products	26	1,255.0	13.6	1.6
Electrical equipment	27	666.2	7.2	0.8
Machinery and equipment nec	28	1,163.4	12.6	1.5
Motor vehicles, trailers, and semi-trailers	29	1,060.8	11.5	1.3
Air and spacecraft and related machinery	303	258.9	2.8	0.3
Railroad, military vehicles, and transport nec	302, 304, and 309	117.2	1.3	0.1
Medical and dental instruments	325	175.1	1.9	0.2
Services		2,812.6	30.5	3.5
IT and other information services	62 - 63	1,720.7	18.7	2.1
Software publishing	58	390.5	4.2	0.5
Scientific research and development	72	701.3	7.6	0.9

GDP = gross domestic product; ISIC, Rev.4 = International Standard Industrial Classification, Revision 4; IT = information technology; KTI = knowledge and technology intensive; nec = not elsewhere classified.

Note(s):
Value added is the amount contributed by a country, an industry, or other entity to the value of a good or service and excludes purchases of domestic and imported materials and inputs. KTI industries include high R&D intensive and medium-high R&D intensive industries based on a classification by the Organisation for Economic Co-operation and Development. The global values above do not include all countries and economies due to limitations in data availability. See Table SKTI-4 for a list of countries and economies for which data are available and Table SKTI-5 through Table SKTI-19 for historical country-level data on these industries.

Source(s):
U.S. Bureau of Economic Analysis, Value Added by Industry, accessed 5 October 2021; IHS Markit, special tabulations (2021) of the Comparative Industry Service.

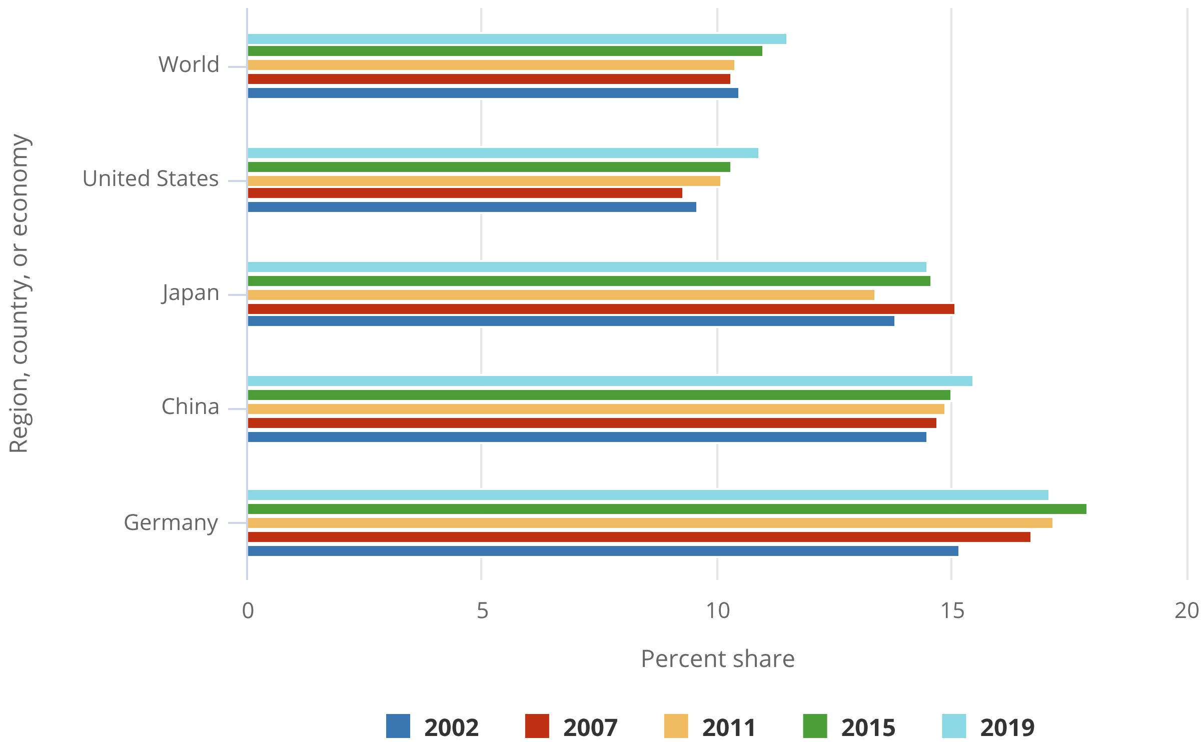
Science and Engineering Indicators

Global KTI production is highly concentrated geographically (Table SKTI-5). The United States and China were the world's largest producers of KTI output in 2019, each with a 25% share of global KTI value added. Japan (8%) and Germany (6%) came next, followed by South Korea (4%), the United Kingdom (3%), and France (2%). These top 7 countries accounted for almost three-fourths (73%) of global KTI value added. Other countries with sizable KTI production in 2019 were India, Italy, and Taiwan, each with a global value-added share between 1.5% and 2.5%.

The contribution of KTI industries to a nation's economy varies among the top KTI producers. In 2019, the KTI share of U.S. GDP was near the global average (11% of GDP) (**Figure KTI-7**). In contrast, Germany's share was considerably larger at 17%. China and Japan also had KTI shares of national GDP that are larger (14%–15%) than the global average. These shares have been slowly increasing in the United States and China. Germany's share has increased from 15% in 2002 to 17% in 2019, and Japan's share has fluctuated between 13% and 15% during this period.

Figure KTI-7

KTI value added as a share of domestic GDP for selected countries and years: 2002–19



GDP = gross domestic product; KTI = knowledge and technology intensive; nec = not elsewhere classified.

Note(s):
Value added is the amount contributed by a country, an industry, or other entity to the value of a good or service and excludes purchases of domestic and imported materials and inputs. KTI industries include high R&D intensive and medium-high R&D intensive industries based on a classification by the Organisation for Economic Co-operation and Development. High R&D intensive industries include air and spacecraft and related machinery; pharmaceuticals; computer, electronic, and optical products; scientific research and development; and software publishing. Medium-high R&D intensive industries include motor vehicles, trailers, and semi-trailers; medical and dental instruments; machinery and equipment nec; chemicals and chemical products; electrical equipment; railroad, military vehicles, and transport nec; and information technology and other information services. The world total does not include all countries and economies due to limitations in data availability. See Table SKTI-4 for a full list of countries and economies in each region for which data are available. China includes Hong Kong.

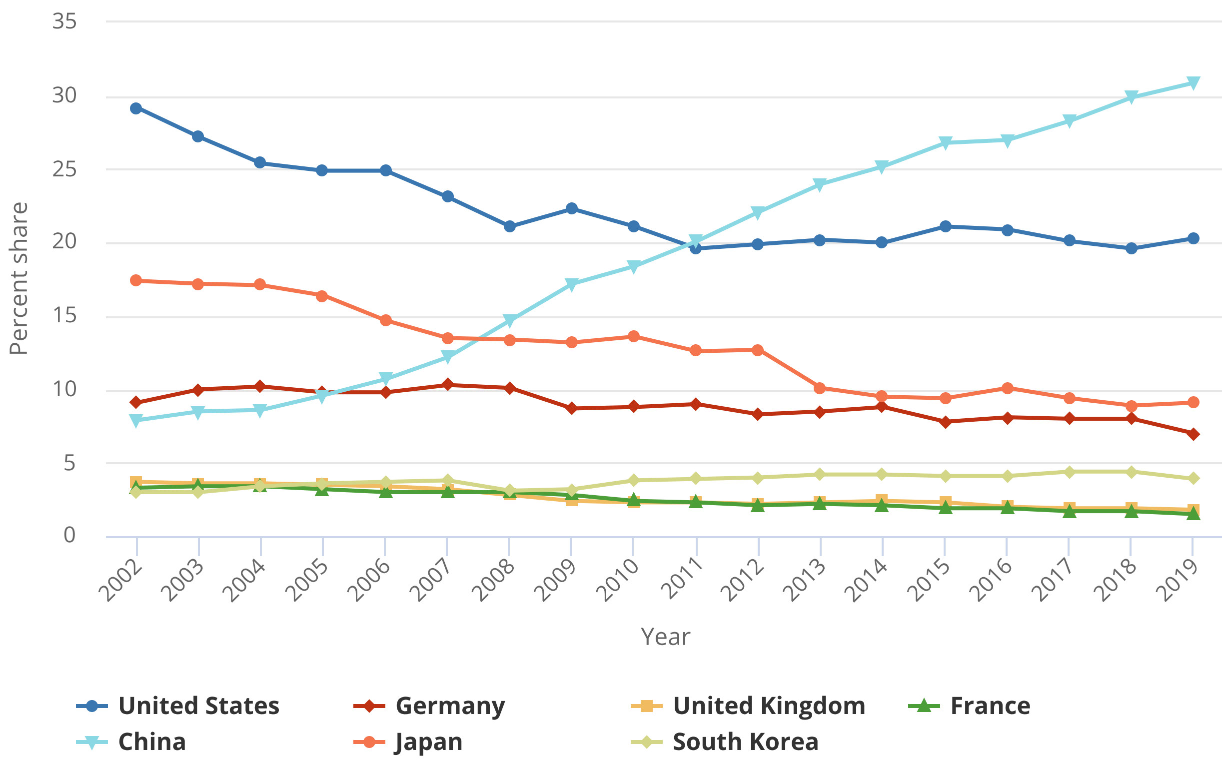
Source(s):
U.S. Bureau of Economic Analysis, Value Added by Industry, accessed 5 October 2021; IHS Markit, special tabulations (2021) of the Comparative Industry Service.

Science and Engineering Indicators

The global value added by KTI manufacturing industries has more than doubled since 2002, most of which is attributable to China (**Figure KTI-8**; Table SKTI-6). China has emerged as a major producer in these industries over the last decade as its global value-added share has increased rapidly from 8% in 2002 to 31% in 2019. The U.S. global share has fluctuated between 20% and 21% since 2011, having declined from 29% in 2002. Japan is also a major producer; however, Japan's production of KTI manufacturing output has experienced declines over this period, and its global share has declined sharply from 17% in 2002 to 9% in 2019. Japan's declines in these industries coincide with slow labor force and economic growth as well as the transfer of production to China and other countries (Funabashi and Kushner 2015).

Figure KTI-8

Country share of global KTI manufacturing value added for selected countries: 2002–19



KTI = knowledge and technology intensive; nec = not elsewhere classified.

Note(s):
Value added is the amount contributed by a country, an industry, or other entity to the value of a good or service and excludes purchases of domestic and imported materials and inputs. KTI industries include high R&D intensive and medium-high R&D intensive industries based on a classification by the Organisation for Economic Co-operation and Development. KTI manufacturing industries include chemicals and chemical products; pharmaceuticals; computer, electronic, and optical products; electrical equipment; machinery and equipment nec; motor vehicles, trailers, and semi-trailers; air and spacecraft and related machinery; railroad, military vehicles, and transport nec; and medical and dental instruments. China includes Hong Kong. See also Table SKTI-6.

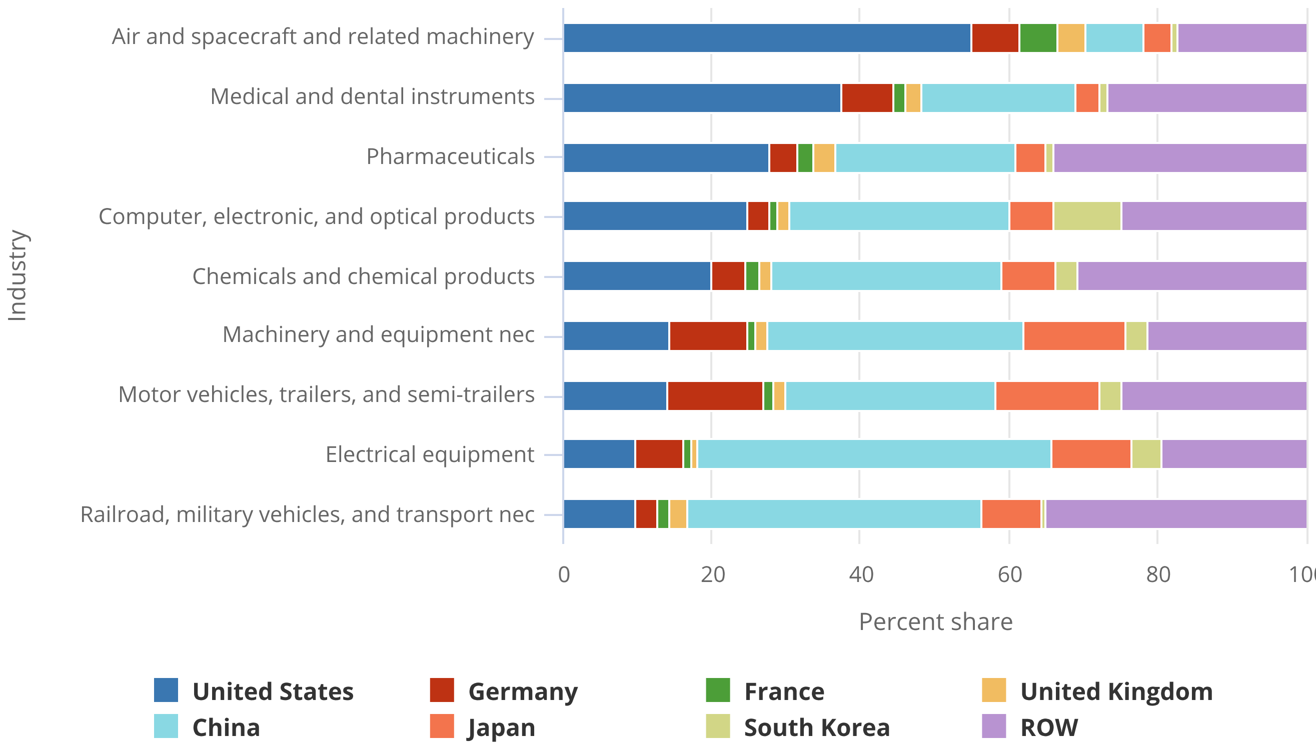
Source(s):
U.S. Bureau of Economic Analysis, Value Added by Industry, accessed 5 October 2021; IHS Markit, special tabulations (2021) of the Comparative Industry Service.

Science and Engineering Indicators

The United States accounted for the largest shares of value added generated by three KTI manufacturing industries worldwide—air and spacecraft, medical and dental instruments, and pharmaceuticals (**Figure KTI-9**; Table SKTI-9, Table SKTI-14, and Table SKTI-16). The United States accounts for 55% of the global value added generated by the air and spacecraft industry, 38% of medical and dental instruments, and 28% of pharmaceuticals. China continues to have a small global presence in manufacturing of air and spacecraft (8% of global value added in 2019) but has markedly increased its global presence in production of medical and dental instruments (from 8% in 2002 to 21% in 2019) as well as pharmaceuticals (from 6% in 2002 to 24% in 2019). The rapidly expanding middle class, reform of China's health care system, and increasing demand for health care have fueled the rapid expansion of China's pharmaceuticals industry (Hsu 2015). Many multinational biopharmaceutical companies have established R&D facilities in China to access the country's domestic market, and a growing number of Chinese companies have increased their investment in R&D (Chen and Zhao 2018).

Figure KTI-9

Country share of global KTI manufacturing value added, by KTI industry: 2019



KTI = knowledge and technology intensive; nec = not elsewhere classified; ROW = rest of world.

Note(s):
Value added is the amount contributed by a country, an industry, or other entity to the value of a good or service and excludes purchases of domestic and imported materials and inputs. KTI industries include high R&D intensive and medium-high R&D intensive industries based on a classification by the Organisation for Economic Co-operation and Development. China includes Hong Kong. See also Table SKTI-8 through Table SKTI-16.

Source(s):
U.S. Bureau of Economic Analysis, Value Added by Industry, accessed 5 October 2021; IHS Markit, special tabulations (2021) of the Comparative Industry Service.

Science and Engineering Indicators

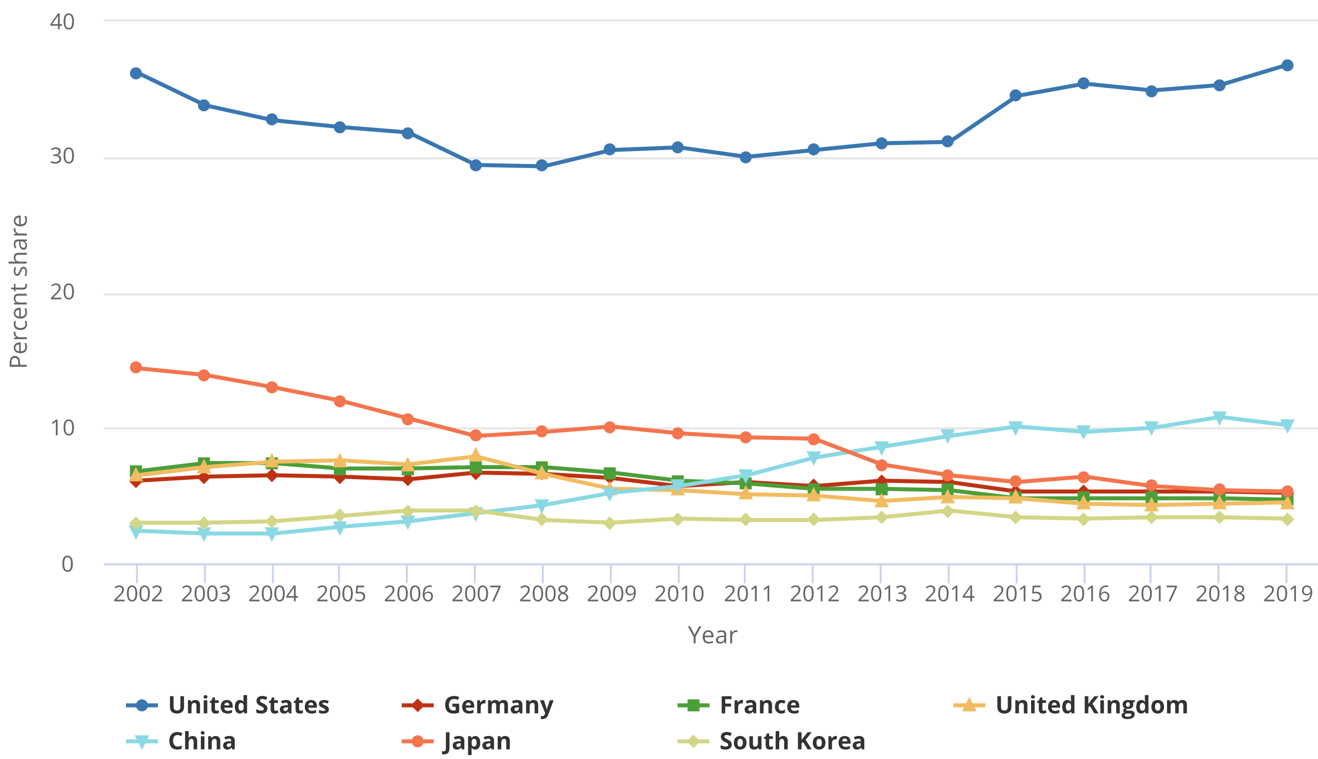
In 2019, China accounted for the largest global shares of value added generated by electrical equipment (48%), railroad and other transport equipment (40%), other machinery and equipment (34%), computer, electronic, and optical products (30%), motor vehicles (28%), and chemicals and chemical products (31%) (**Figure KTI-9**). Much of these industries' rapid growth over the last decade is attributable to China. The value added generated by the electrical equipment industry worldwide grew nearly threefold since 2002, with China's global share quadrupling from 12% to 48% (Table SKTI-11). China's global share also more than quadrupled in the other machinery and equipment industry, from 8% in 2002 to 34% in 2019 (Table SKTI-12).

China's computer, electronic, and optical products value added has grown nearly eightfold since 2002, becoming the world's largest producer in 2014 and remaining so ever since (Table SKTI-10). The United States is the second-largest producer (25% global value-added share). Japan's value added in this industry has declined, and so has its global share (from 18% in 2002 to 6% in 2019). Other Asian countries—South Korea, Taiwan, India, Indonesia, Malaysia, the Philippines, Singapore, Thailand, and Vietnam—have also increased production in this industry, jointly accounting for 23% of the global value added in 2019.

The United States leads global production in KTI services industries, accounting for 37% of the global value added generated by these industries in 2019 (**Figure KTI-10**; Table SKTI-7). The U.S. global share of value added generated by KTI services has increased over the last decade after a decline in the early 2000s and stabilization around 30%. Other major KTI producers have global shares that are much lower. Germany, France, and the United Kingdom have global shares that have remained around 4%–6% since 2010. China's global share has fluctuated between 10% and 11% since 2015, having increased from 2% in 2002. In contrast, Japan's share has declined substantially, from 14% in 2002 to 5% in 2019.

Figure KTI-10

Country share of global KTI services value added for selected countries: 2002–19



KTI = knowledge and technology intensive.

Note(s):
Value added is the amount contributed by a country, an industry, or other entity to the value of a good or service and excludes purchases of domestic and imported materials and inputs. KTI industries include high R&D intensive and medium-high R&D intensive industries based on a classification by the Organisation for Economic Co-operation and Development. KTI services industries include information technology and other information services, software publishing, and scientific research and development. China includes Hong Kong. See also Table SKTI-7.

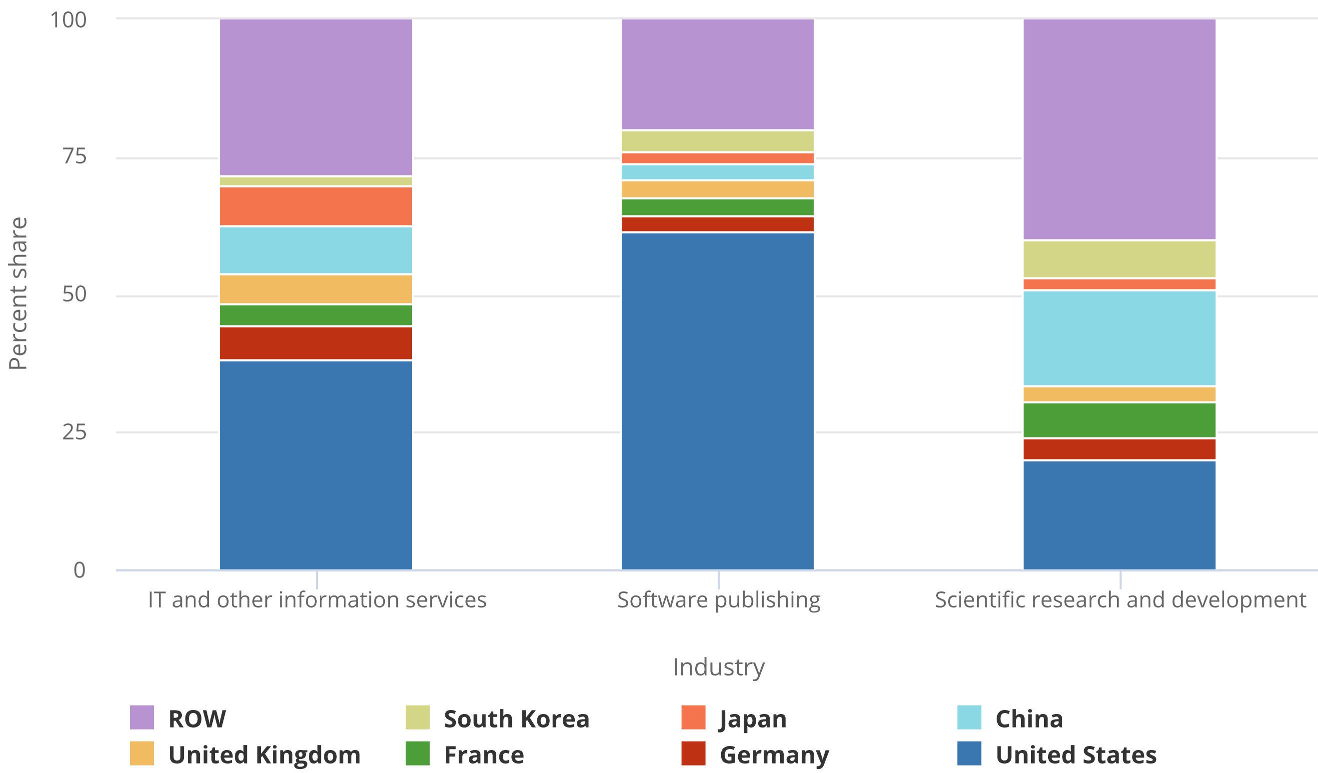
Source(s):
U.S. Bureau of Economic Analysis, Value Added by Industry, accessed 5 October 2021; IHS Markit, special tabulations (2021) of the Comparative Industry Service.

Science and Engineering Indicators

The United States accounted for the largest shares of value added generated worldwide by each of the three KTI services industries in 2019: software publishing (61% global share), IT and other information services (38%), and scientific research and development (20%) (**Figure KTI-11**; Table SKTI-18, Table SKTI-17, and Table SKTI-19). China and the other major KTI producers each accounted for 2%–4% of the global software publishing value added. These countries had larger shares of global value added that were generated by IT and other information services compared to software publishing (4%–9% each in 2019), except for South Korea (2%). The 2019 value added generated by the scientific research and development industry was more widely spread geographically; China's global value-added share (18%) was just below that of the United States (20%), whereas South Korea and France each had global shares of 6%–7%.

Figure KTI-11

Country share of global KTI services value added, by KTI service industry: 2019



IT = information technology; KTI = knowledge and technology intensive; ROW = rest of world.

Note(s):
Value added is the amount contributed by a country, an industry, or other entity to the value of a good or service and excludes purchases of domestic and imported materials and inputs. KTI industries include high R&D intensive and medium-high R&D intensive industries based on a classification by the Organisation for Economic Co-operation and Development. China includes Hong Kong. See also Table SKTI-17 through Table SKTI-19.

Source(s):
U.S. Bureau of Economic Analysis, Value Added by Industry, accessed 5 October 2021; IHS Markit, special tabulations (2021) of the Comparative Industry Service.

Science and Engineering Indicators

Global Trade in Knowledge- and Technology-Intensive Output

Exports are an indicator of a country's competitiveness in the world market. The goods and services produced or used in production by KTI industries are produced within global value chains (GVCs) with inputs from many countries. A significant volume of trade is in intermediate inputs—the goods and services used in the production process to produce other goods and services—that are exported to other countries for further production (Miroudot, Lanz, and Ragoussis 2009); since 2002, trade in intermediate inputs has tripled (Lund et al. 2020).

GVCs are global production arrangements comprising R&D, design, production, logistics, marketing, and related activities that take place across regions to bring a product or service from conception to its final form (OECD 2012). Proximity to markets and raw materials, transportation costs, labor costs, access to skilled workers, government regulations, and technological capabilities are among factors that influence the location of production activities (Donofrio and Whitefoot 2015). GVCs benefit both participating firms and countries through efficiency gains from specialization and economies of scale and lower prices (Andrews, Gal, and Witheridge 2018). These arrangements create opportunities for countries to partake in global production by specializing in segments of production in which they have a comparative advantage.

Gross trade flows provide useful insights on volume of trade and trading patterns across countries. However, these flows do not provide information to gauge the value contributed by any country in the production chain (Koopman, Wang, and Wei 2014). Value-added trade is the featured measure of trade in this section. It measures the countries' contributions in the production chain separately from the total value of the traded products, thus providing useful insights into the production and trade relations between countries.

This section presents new analysis on globalization of U.S. KTI industries, focusing on their use of foreign intermediate inputs. This analysis is especially relevant in light of the COVID-19 pandemic, which has revived discussions of efficiency, stability, risk and resilience in GVCs (e.g., OECD 2020, Arriola et al. 2020, Lund et al. 2020).[11]

The source for the trade data is the OECD Trade in Value Added (TiVA) database.[12] A description of this database is provided in the **Technical Appendix**. Since the latest year of data in this database is 2018, to supplement this analysis, this section also presents experimental TiVA statistics based on a single-country framework that are under development through a new partnership between the National Center for Science and Engineering Statistics (NCSES) and BEA. (See sidebar **U.S. Trade in Value Added: A Single-Country Perspective**.)

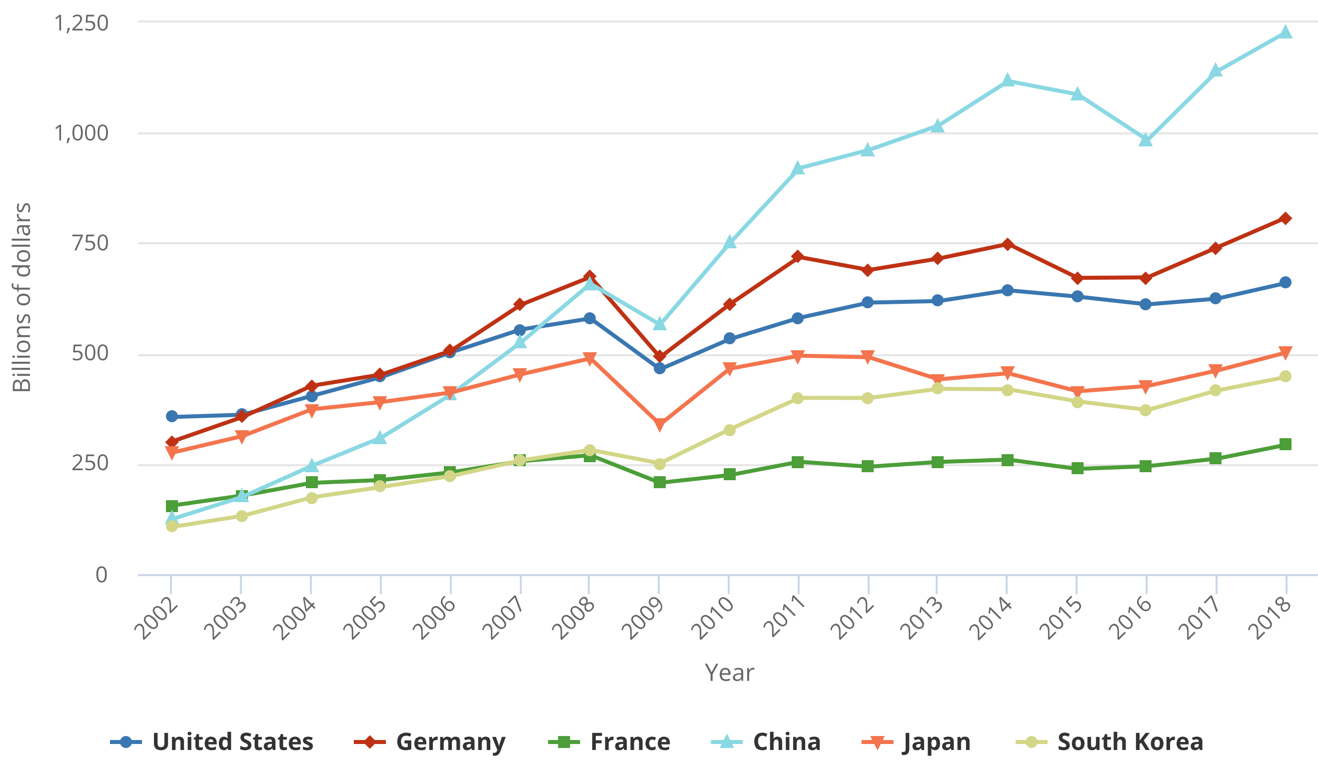
Gross Flows of Trade in KTI Output

Comparative country data on gross exports by KTI industries are available for most, but not all, KTI manufacturing industries and the IT and other information services industry. There are no data available on exports by the medical and dental instruments industry. Because the OECD trade data are insufficiently detailed for the other KTI services industries (software publishing and scientific research and development), the analysis on KTI services trade is supplemented with U.S. data from BEA's International Economic Accounts.

Global exports of KTI industries were over $7.4 trillion in 2018 (**Figure KTI-12**; Table SKTI-20). China is the largest exporter of KTI products with a 17% share of global exports, followed by Germany (11%). The United States (9%) is the third-largest exporter, followed by Japan (7%) and South Korea (6%). These top 5 exporters of KTI products accounted for almost half of all KTI exports in 2018. Other countries with sizable export shares are France, Mexico, Taiwan, Italy, Ireland, India, the United Kingdom, Switzerland, the Netherlands, Singapore, Spain, Canada, and Thailand (each with a 2%–4% global share in 2018).

Figure KTI-12

Gross exports of KTI industries, by selected country: 2002–18



KTI = knowledge and technology intensive; nec = not elsewhere classified.

Note(s):
Data are available for the following KTI industries: chemicals and chemical products; pharmaceuticals; computer, electronic, and optical products; electrical equipment; machinery and equipment nec; motor vehicles, trailers, and semi-trailers; other transport equipment; and information technology and other information services. See also Table SKTI-20.

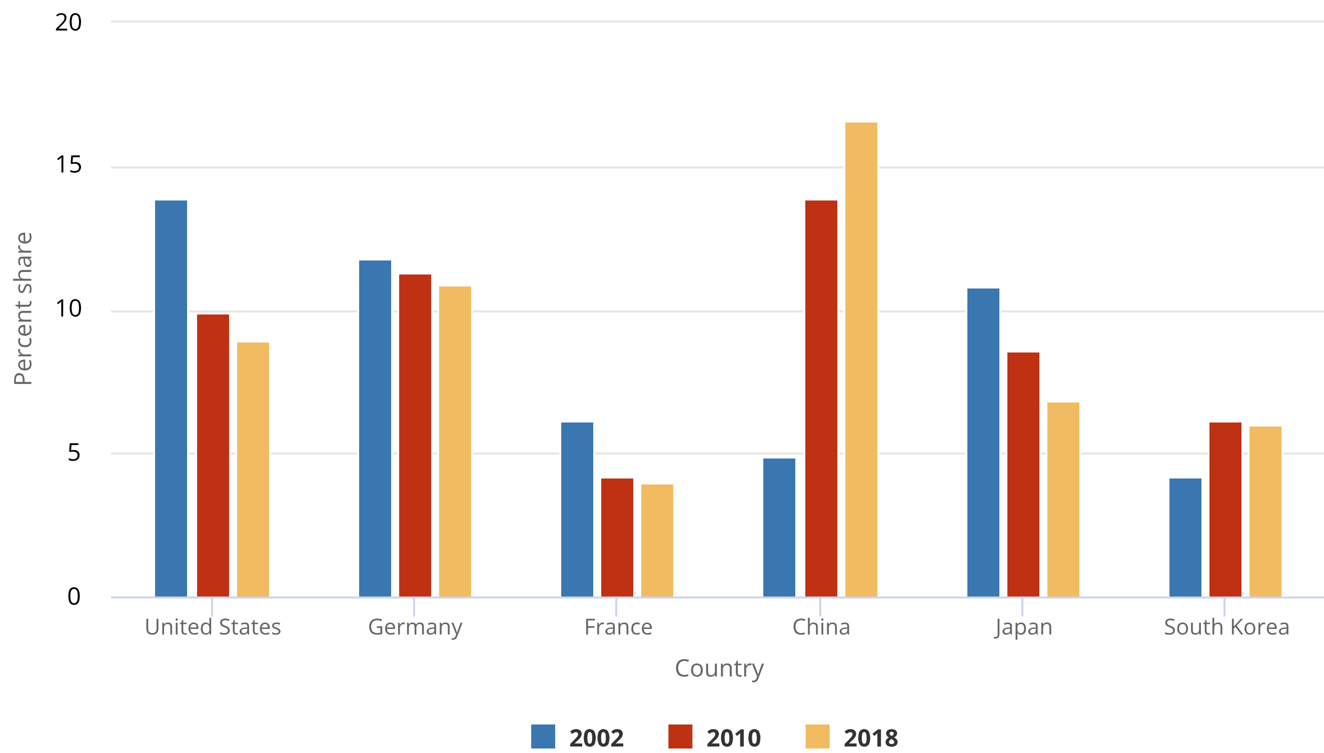
Source(s):
Organisation for Economic Co-operation and Development, 2021 Trade in Value Added Principal Indicators (2021 edition), accessed 27 November 2021.

Science and Engineering Indicators

World exports of KTI products have increased nearly threefold since 2002 (Table SKTI-20). China has accounted for most of this increase. China's KTI exports increased nearly 10-fold, and its global share rose from 5% in 2002 to 17% in 2018 (**Figure KTI-13**). KTI exports from other Asian countries— including South Korea, Thailand, Vietnam and India—have also increased rapidly during this period. The slower growth in exports by other major exporters compared to these Asian countries has resulted in declines in their global export shares, most notably for the United States (from 14% in 2002 to 9% in 2018).

Figure KTI-13

Country share of global KTI exports, by selected countries: 2002, 2010, and 2018



KTI = knowledge and technology intensive; nec = not elsewhere classified.

Note(s):
Global KTI exports include exports of chemicals and chemical products; pharmaceuticals; computer, electronic, and optical products; electrical equipment; machinery and equipment nec; motor vehicles, trailers, and semi-trailers; other transport equipment; and information technology and other information services. China includes Hong Kong. See also Table SKTI-20.

Source(s):
Organisation for Economic Co-operation and Development, Trade in Value Added Principal Indicators (2021 edition), accessed 27 November 2021.

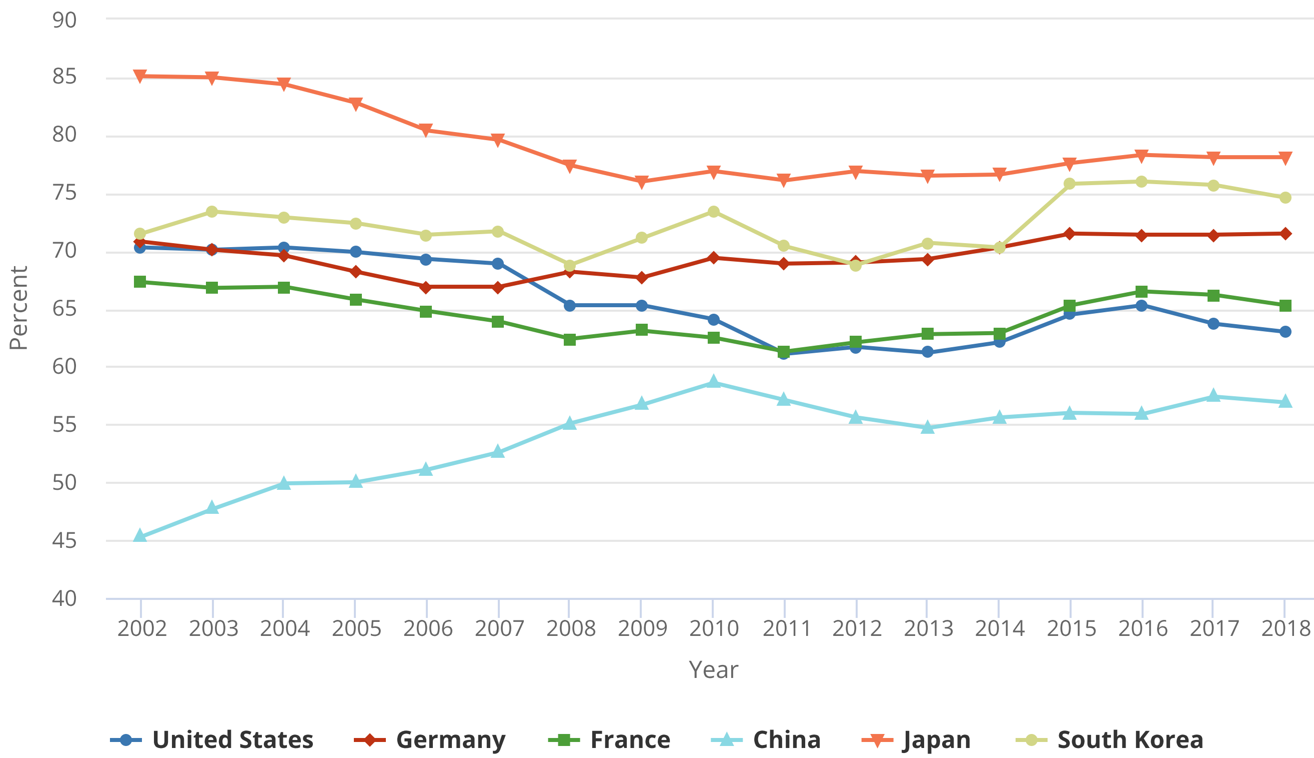
Science and Engineering Indicators

China is the hub of "Factory Asia"—the electronics goods production network centered in East Asia—and plays a central role in this network as the major location of final assembly and as the largest importer and exporter of electronic components (WTO/IDE-JETRO 2011). China imports and exports inputs and components from other Asian economies—notably, Japan, South Korea, Singapore, and Taiwan (Frederick and Lee 2017). China has a global manufacturing scale, a network of suppliers, a large labor force of skilled production workers, and the ability to quickly ramp up production required for many electronic products that have short development cycles (Donofrio and Whitefoot 2015). China has also become a center for manufacturing and assembly of many other KTI products, including electrical equipment, other machinery and equipment, and motor vehicles.

KTI manufacturing exports comprise a large share of manufacturing exports (more than 50%) for all major exporters of KTI products (**Figure KTI-14**). This share is lowest for China (57% in 2018) and largest for Japan (78%). Exports by KTI manufacturing industries comprised 63% of all U.S. manufacturing exports in 2018. The KTI share of manufacturing exports has declined since the early 2000s for some of the major KTI exporters but has stabilized after 2010.

Figure KTI-14

KTI manufacturing exports as a share of all manufacturing exports, by selected country: 2002–18



KTI = knowledge and technology intensive; nec = not elsewhere classified.

Note(s):
KTI manufacturing exports include exports of chemicals and chemical products; pharmaceuticals; computer, electronic, and optical products; electrical equipment; machinery and equipment nec; motor vehicles, trailers, and semi-trailers; and other transport equipment. See also Table SKTI-20.

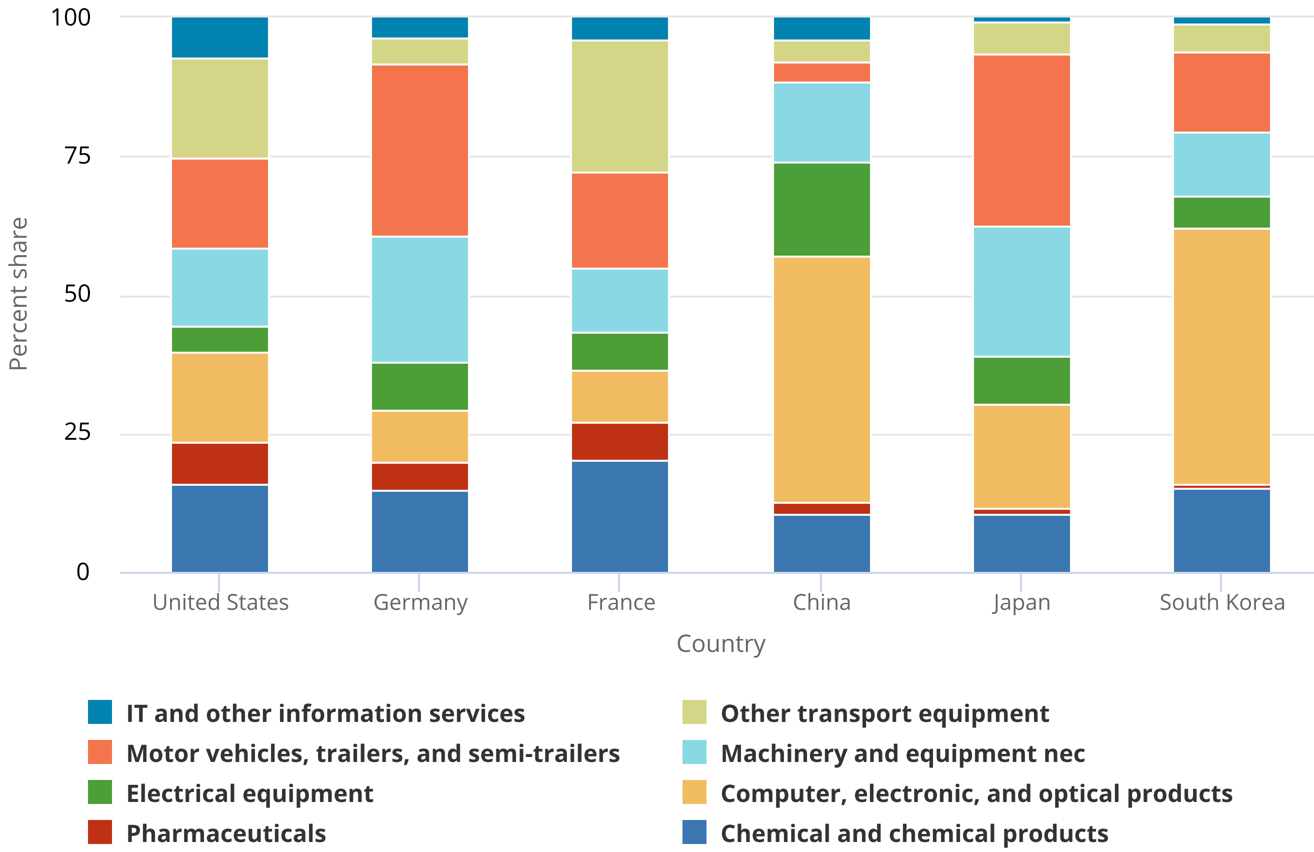
Source(s):
Organisation for Economic Co-operation and Development, Trade in Value Added Principal Indicators (2021 edition), accessed 27 November 2021.

Science and Engineering Indicators

The industry composition of KTI exports varies by country (**Figure KTI-15**). For China and South Korea, exports by the computer, electronic, and optical products industry dominate their KTI exports (44%–46% share). Exports by the motor vehicles industry account for more than 30% of KTI exports of Germany and Japan. The U.S. KTI exports are spread more uniformly across KTI industries, with each of the following accounting for 14%–18% of U.S. KTI exports: exports of motor vehicles; computer, electronic, and optical products; chemicals and chemical products; other machinery and equipment; and other transport equipment. Pharmaceuticals and IT and other information services each account for more than 7% of U.S. KTI exports.

Figure KTI-15

Industry composition of country KTI exports for selected countries: 2018



IT = information technology; KTI = knowledge and technology intensive; nec = not elsewhere classified.

Note(s):
China includes Hong Kong. See also Table SKTI-20.

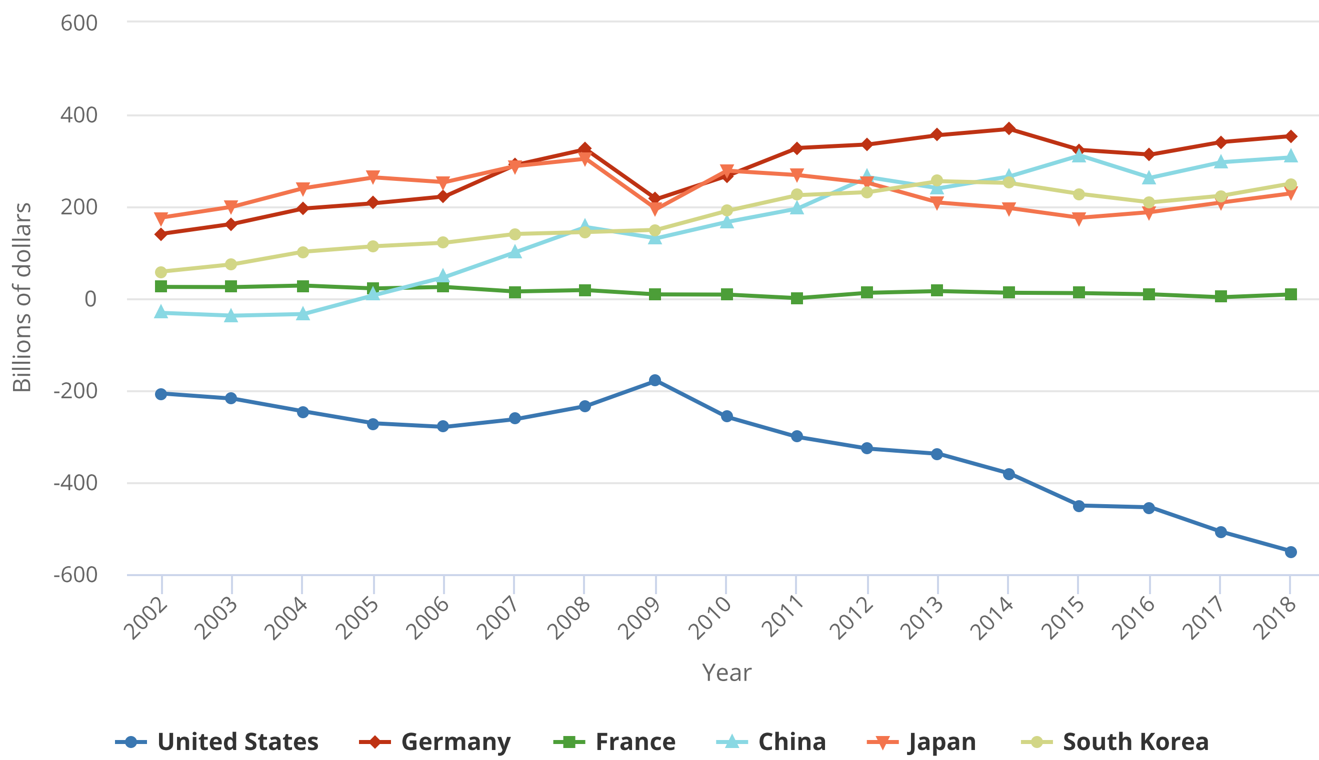
Source(s):
Organisation for Economic Co-operation and Development, Trade in Value Added Principal Indicators (2021 edition), accessed 27 November 2021.

Science and Engineering Indicators

The United States is the only country among major KTI exporters with a large and growing deficit in KTI trade (**Figure KTI-16**). The U.S. trade deficit was $550 billion in 2018, of which $528 billion was in output produced by KTI manufacturing industries and $22 billion by the IT and other information services industry. (The OECD TiVA database reports U.S. exports of IT and other information services industry at $48.3 billion and imports at $70.2 billion.) Moreover, the U.S. trade deficit has widened by almost $300 billion compared to the average deficit of about $250 billion during the 2002–10 period. China had a KTI trade deficit until 2004 but since then has gradually increased its trade surplus. Japan, Germany, and South Korea have substantial KTI trade surpluses, whereas France has a comparatively smaller surplus.

Figure KTI-16

KTI trade balance, by selected country: 2002–18



KTI = knowledge and technology intensive; nec = not elsewhere classified.

Note(s):
Data are available for the following KTI industries: chemicals and chemical products; pharmaceuticals; computer, electronic, and optical products; electrical equipment; machinery and equipment nec; motor vehicles, trailers, and semi-trailers; other transport equipment; and information technology and other information services. See also Table SKTI-20.

Source(s):
Organisation for Economic Co-operation and Development, Trade in Value Added Principal Indicators (2021 edition), accessed 27 November 2021.

Science and Engineering Indicators

The U.S. trade deficit, while sizable, may be lower when considering trade of other KTI services (software publishing and scientific research and development services). BEA collects and reports data on trade in services by service type. Although not directly comparable with the exports by services industries reported in the OECD TiVA database, these data provide useful insights on trends of KTI services trade. These data show a positive and growing trade balance in cloud computing and data storage services; database and other information services; computer software, including end-user licenses and customization; R&D services; and licenses for reproduction or distribution of computer software and use of R&D outcomes (**Figure KTI-17**). The trade surplus in these services has doubled since 2006 (first year of available data), from $34 billion in 2006 to $74 billion in 2020.

Figure KTI-17

Exports, imports, and trade balance of KTI services for the United States: Selected years, 2006–20

KTI = knowledge and technology intensive.

Note(s):
These data are not reported by industry but by type of service. This figure reports data on U.S. trade in services for the following KTI-related services: cloud computing and data storage services; database and other information services; computer software, including end-user licenses and customization; research and development services; and licenses for reproduction or distribution of computer software and use of research and development outcomes.

Source(s):
Bureau of Economic Analysis, Table 2.1. U.S. Trade in Services, by Type of Service, accessed 30 November 2021.

Science and Engineering Indicators

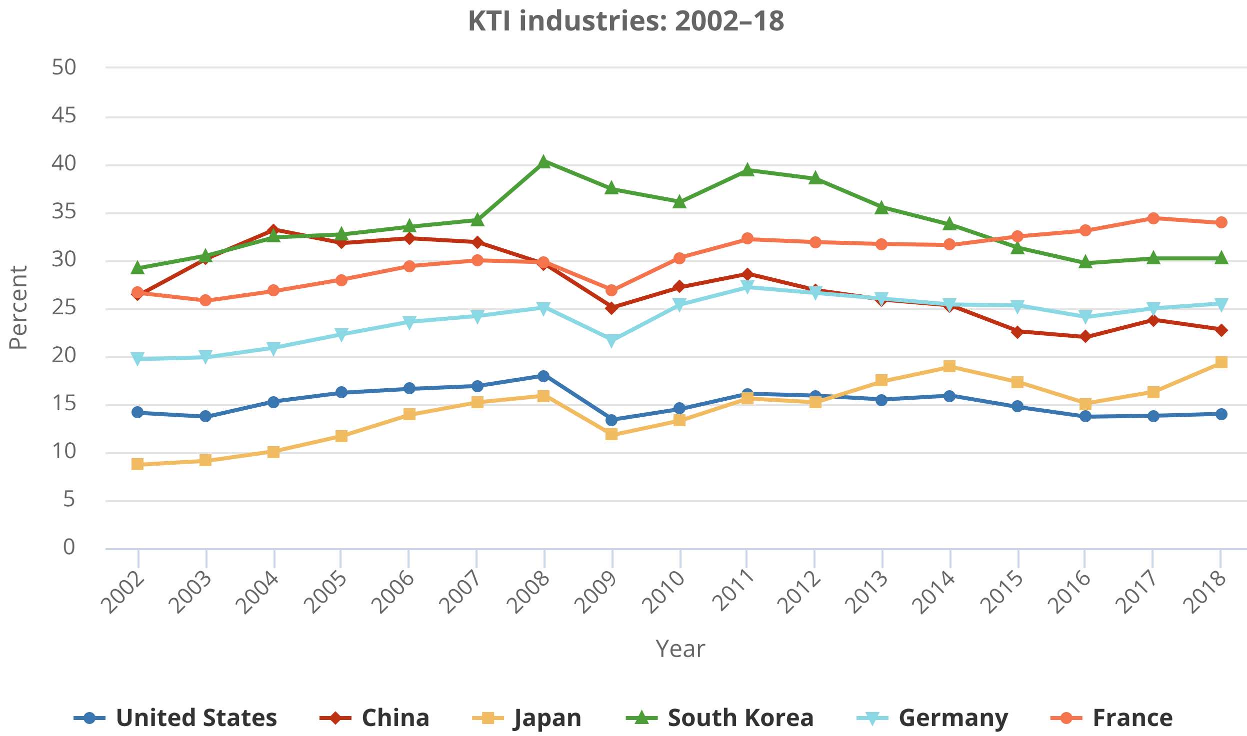
Value-Added Trade in KTI Output

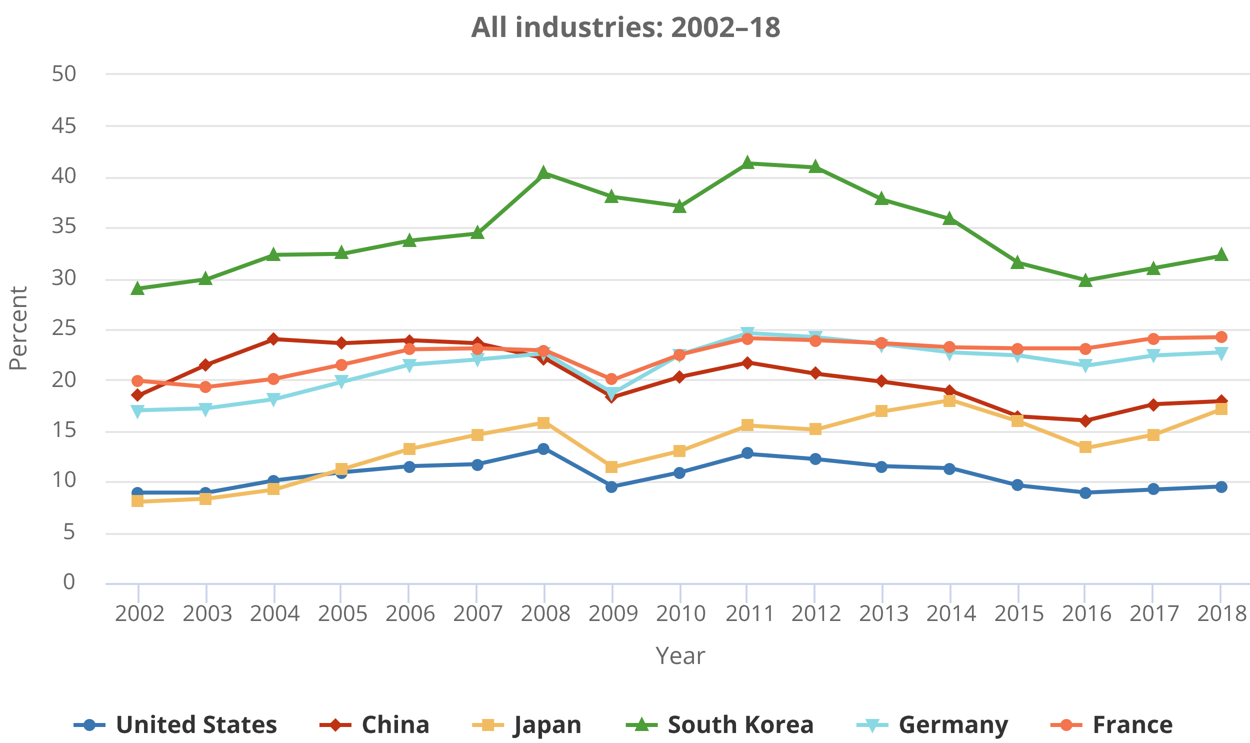
Because not all of the value of gross exports is generated in the exporting country, an important indicator of globalization in production is the foreign value-added content (or foreign value-added share) of gross exports. This indicator captures the value of imported intermediate goods and services that are embodied in a domestic industry's exports.

The average foreign value-added content share of U.S. KTI industries over the 2002–18 period is about 15%, higher than the average across all industries (11%) (**Figure KTI-18**). Germany, France, China, and South Korea have higher foreign content shares of their KTI exports compared to the United States and Japan.

Figure KTI-18

Average foreign value-added share of KTI and total gross exports for selected countries: 2002–18





KTI = knowledge and technology intensive; nec = not elsewhere classified.

Note(s):
A country's average foreign value-added share of gross exports for KTI industries is the weighted average of the country's foreign value-added shares of the following industries: chemicals and chemical products; pharmaceuticals; computer, electronic, and optical products; electrical equipment; machinery and equipment nec; motor vehicles, trailers, and semi-trailers; other transport equipment; and information technology and other information services. China includes Hong Kong.

Source(s):
Organisation for Economic Co-operation and Development, Trade in Value Added Principal Indicators (2021 edition), accessed 27 November 2021.

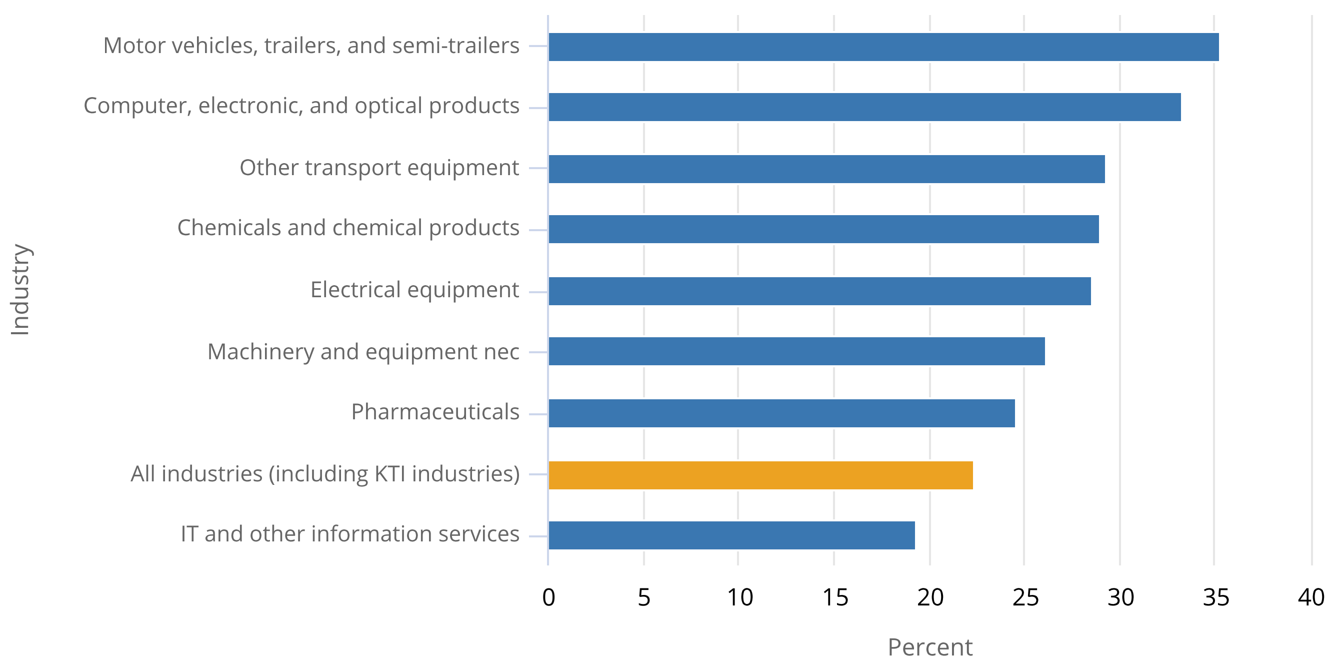
Science and Engineering Indicators

The average foreign value-added content of gross exports in KTI industries (and overall industries) has gradually declined for many major economies since 2011, leveling off after 2016. The decline is more pronounced in South Korea and China, where it started earlier than 2011. China's average foreign content share of gross exports for KTI industries declined from a high of 33% in 2004 to 23% in 2015 and has since fluctuated around 23%. This decline is largely a result of China's policy efforts to reform its science and technology (S&T) system and build capacity to produce domestically many of the high-technology components that it imports from other countries (Chen and Shih 2005). The decline in the average foreign content share of U.S. KTI gross exports is more modest, from a high of 18% in 2008 to 14% in 2016, and it has since remained at 14%.

Among KTI industries, motor vehicles and computer, electronic, and optical products are the two most globally integrated industries (i.e., industries with the highest average shares of foreign value-added content in gross exports across all countries) (**Figure KTI-19**). The average foreign content share of gross exports in these two industries is over 30%. Other manufacturing KTI industries have foreign content shares that range from 25% to 29%. The IT and other information services industry has the lowest foreign content share of gross exports among KTI industries at 19%. By the nature of their production processes, services-producing industries in general rely more on labor and capital and less on purchased intermediate inputs (whether foreign or domestic) than goods-producing industries.

Figure KTI-19

Average foreign value-added share of global KTI gross exports, by KTI industry: 2018



IT = information technology; KTI = knowledge and technology intensive; nec = not elsewhere classified.

Note(s):
The average foreign value added share is the weighted average of 66 countries and the rest of the world as covered by the Organisation for Economic Co-operation and Development's Trade in Value Added database.

Source(s):
Organisation for Economic Co-operation and Development, Trade in Value Added Principal Indicators (2021 edition), accessed 27 November 2021.

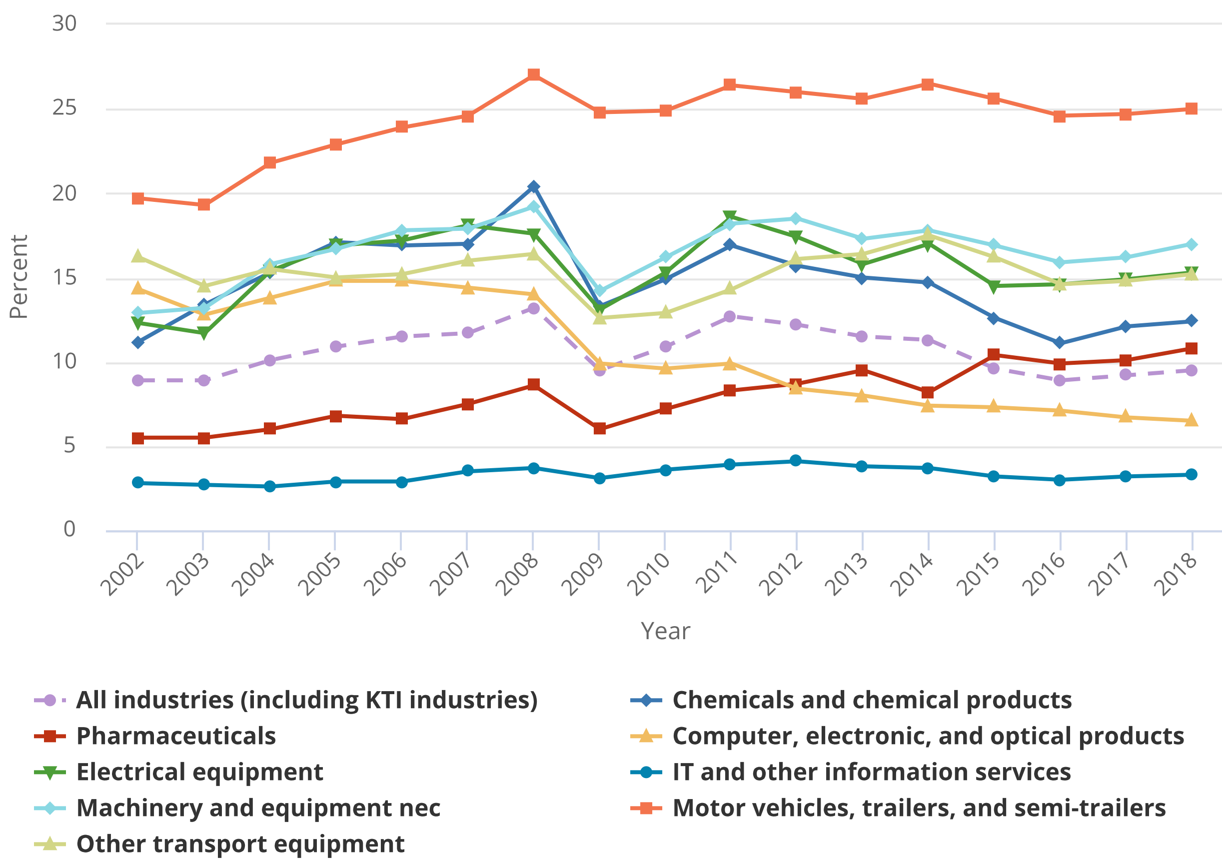
Science and Engineering Indicators

Global value chains are prevalent in the computer, electronic, and optical products industry because components are modular and generally low weight, which keeps shipping costs low (OECD 2012). A significant portion of production of electronic products with short development cycles has moved to Asian countries like China that are able to scale up production quickly. Production of motor vehicles, on the other hand, is generally located closer to the final markets to keep transportation costs low and to better understand customers' needs as it relates to motor vehicle design (Donofrio and Whitefoot 2015).

In the United States, the motor vehicle industry is the most reliant on foreign intermediate inputs. Since 2007, 25% or more of the value of motor vehicles exports each year was foreign value added (**Figure KTI-20**). The foreign content share in gross exports for most U.S. KTI manufacturing industries varies between 10% and 20%. Among U.S. KTI manufacturing industries, computer, electronic, and optical products and pharmaceuticals have the lowest foreign content share in exports.

Figure KTI-20

Foreign value added share of U.S. gross exports for KTI industries: 2002–18



IT = information technology; KTI = knowledge and technology intensive; nec = not elsewhere classified.

Source(s):
Organisation for Economic Co-operation and Development, Trade in Value Added Principal Indicators (2021 edition), accessed 27 November 2021.

Science and Engineering Indicators

The computer, electronic, and optical products industry in the United States has a much smaller share of foreign content value in gross exports compared with other countries (15% at its highest [2005, 2006] and under 7% more recently [2017, 2018], compared to over 30% average across all countries). The foreign content share of this industry declined sharply in 2009—as it did in all other KTI industries during the Great Recession—and has continued to decline more recently. Increased domestic sourcing of intermediate inputs and changes in commodity prices are among factors that affect this ratio.

The IT and other information services industry in the United States has the lowest foreign content share of gross exports among KTI industries. The foreign content share of exports from this industry has been stable at 3%–4% since 2002.

SIDEBAR

U.S. Trade in Value Added: A Single-Country Perspective

This sidebar presents new analysis on value-added trade for the United States. It complements the analysis based on the Organisation of Economic Co-operation and Development (OECD) Trade in Value Added (TiVA) database and is based on a new set of economic statistics for the United States. These experimental statistics are being developed through a new partnership between the National Center for Science and Engineering Statistics and the U.S. Bureau of Economic Analysis.

TiVA statistics provide a useful way of decomposing both the global and domestic elements of a global value chain. Thus, these data enable supply chain analysis, including analysis of shifts in production patterns and changes in value chain participation over time.

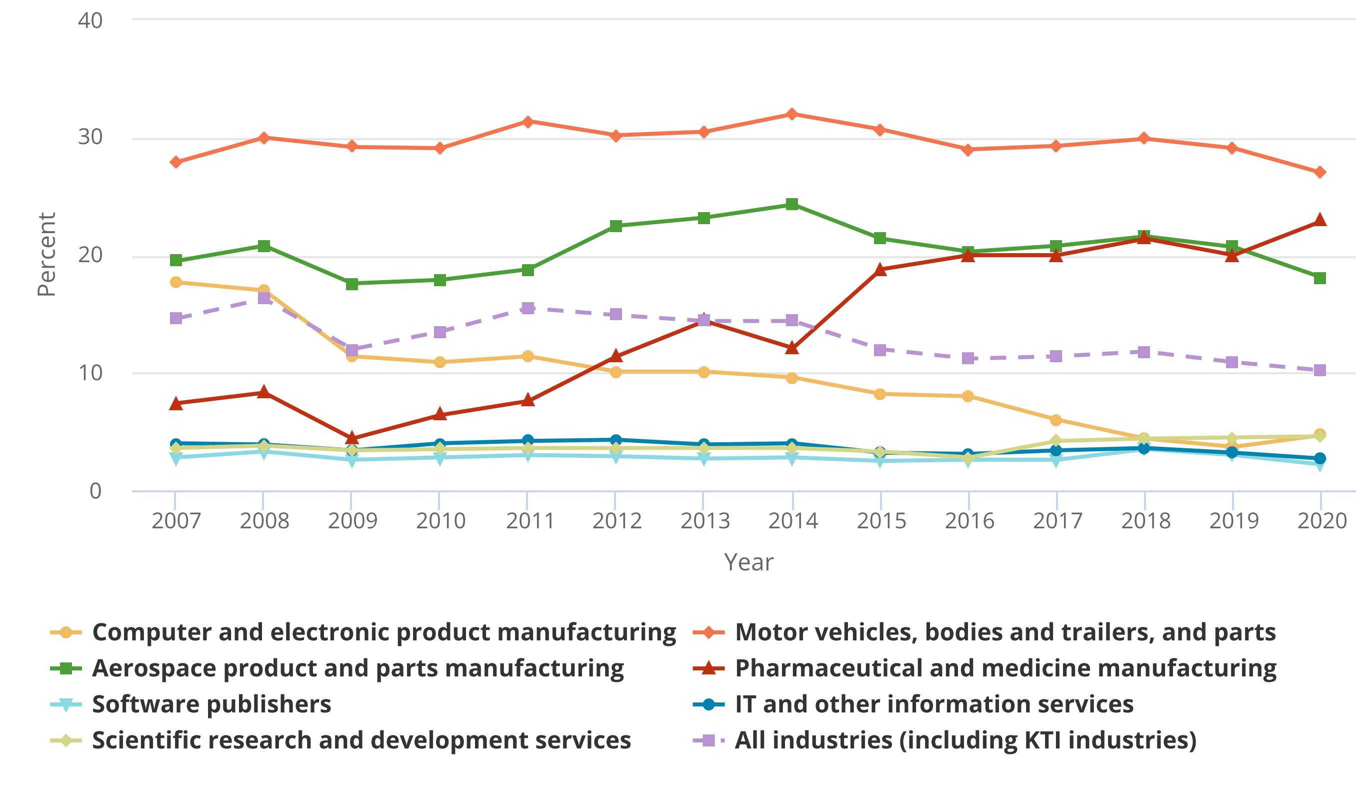
The experimental statistics are developed within a single-country framework (e.g., Chen et al. 2012; Tang, Wang, and Wang 2014; Ma, Wang, and Zhu 2015) using the Supply-Use Tables (SUTs) for the United States and U.S. bilateral trade data. The SUTs show the total domestic supply of goods and services from both domestic and foreign producers and their use across the U.S. economy (Young et al. 2015). Gross exports can be decomposed into domestic value added and foreign content. By integrating bilateral trade data, the foreign content can be further assigned to various countries and regions.

Value-added trade statistics developed within a multi-country framework (e.g., Stehrer 2012; Johnson and Noguera 2012; Koopman, Wang, and Wei 2014) provide a more nuanced view of trade than a single-country framework by accounting for the full global value chain spanning all industries and countries. However, the single-country framework offers several advantages. Most notably, results can be more timely, with more industry detail, and more consistent with official statistics because the results rely exclusively on data produced within the U.S. statistical system.

The new data show that the trends presented earlier in the report continue through 2019 (**Figure KTI-E**). In addition, new data for scientific research and development services and software publishing show that the foreign content share of gross exports for these industries is much lower compared to the other U.S. knowledge- and technology-intensive industries. Note that foreign content shares in this framework differ from those reported in the OECD TiVA database because the single-country model does not fully trace the supply chain.

Figure KTI-E

Imported content share of gross exports by U.S. KTI industry: 2007–20



IT = information technology; KTI = knowledge and technology intensive.

Note(s):
These are prototype statistics and are subject to revision. The industry data are based on the North American Industry Classification System.

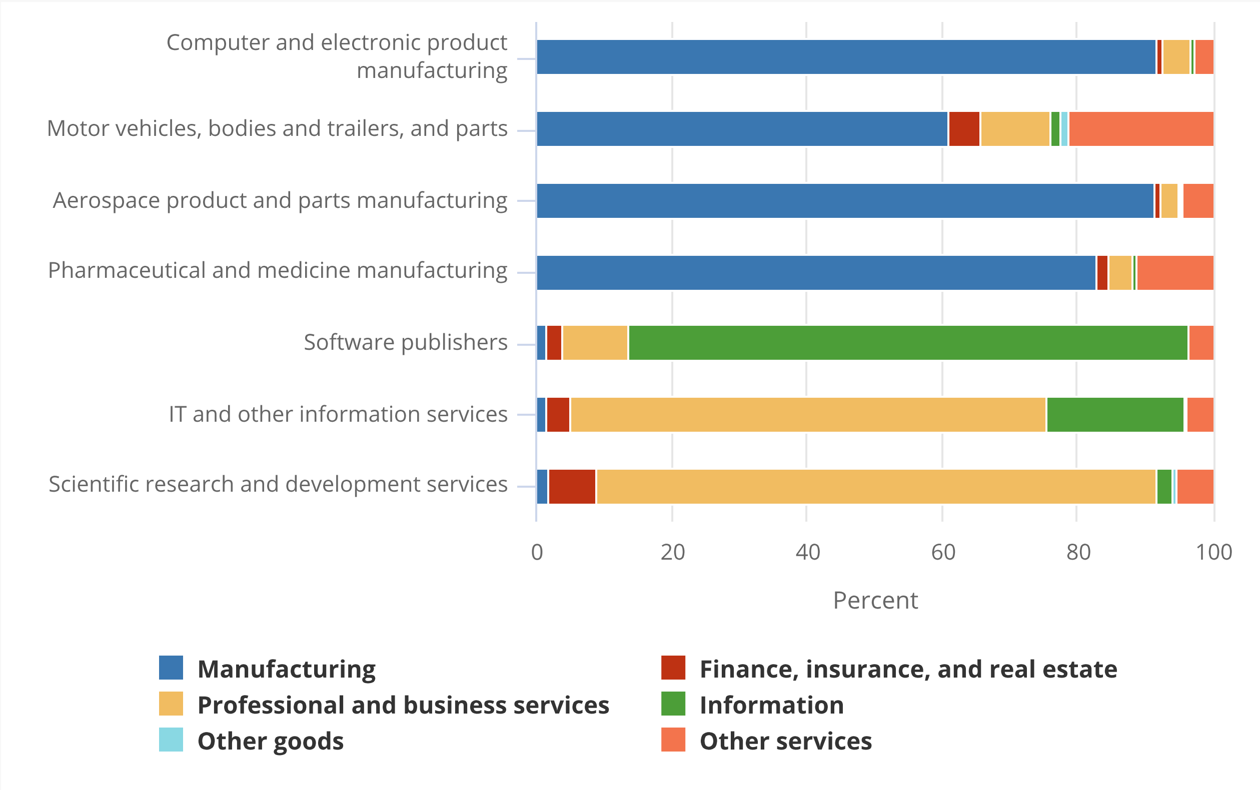
Source(s):
U.S. Bureau of Economic Analysis, Trade in Value Added Data, https://www.bea.gov/data/special-topics/global-value-chains, accessed 25 January 2022.

Science and Engineering Indicators

In addition to reliance on foreign inputs, these statistics also show how the industries interact domestically to produce the domestic value portion of the gross exports (**Figure KTI-F**). For example, almost 60% of the domestic value added in gross exports of the motor vehicles industry is manufacturing value added, while the rest is a combination of other goods and services (including finance and insurance and professional and business services). More than 80% of the domestic value in gross exports of the software publishing industry is information services.

Figure KTI-F

Domestic value-added content of gross exports, by exporting KTI industry and source sector: 2020



IT = information technology; KTI = knowledge and technology intensive.

Note(s):
These are prototype statistics and are subject to revision. The industry data are based on the North American Industry Classification System.

Source(s):
U.S. Bureau of Economic Analysis, Trade in Value Added Data, https://www.bea.gov/data/special-topics/global-value-chains, accessed 25 January 2022.

Science and Engineering Indicators

Enabling Technologies

Enabling technologies are discoveries arising from advanced S&E activity that allow the creation or improvement of products and services across a wide product scope (Teece 2016). Given the ability for these technologies to reshape existing markets, identifying their role and prevalence within regional economies is important for determining economic growth potential in emerging KTI industries. For example, according to the European Commission's (EC's) Joint Research Centre, regional specialization in key enabling technologies—that is, technologies identified by EC as drivers of future economic competitiveness, such as industrial biotechnology and nanotechnologies—directly affects economic growth, while specialization in fast-growing technologies increases economic growth only through downstream effects on a region's innovation performance (e.g., patents) (Evangelista, Meliciani, and Vezzani 2015; Montresor and Quatraro 2015).

AI and biotechnology are two enabling technologies that are essential drivers of U.S. economic activity and competitiveness. For example, biotechnology has been key to the development of coronavirus research and COVID-19 vaccines (see *2022 Indicators* reports, "[2022] Invention, Knowledge Transfer, and Innovation" and "[2022] Publications Output: U.S. Trends and International Comparisons," for information on the COVID-19 vaccine development). Although both of these enabling technologies have been important to U.S. economic growth, they differ in terms of development and use throughout the U.S. economy.

In this section, the roles of AI and biotechnology in the U.S. economy are analyzed to identify trends that indicate regional economic competitiveness related to these technologies. The analysis focuses on three primary lenses for each technology: (1) investment at the global and national level, (2) demand for workers with technology-related skills, and (3) patents. Additional analysis is performed on the adoption of AI technologies within U.S. businesses and on the economic impacts of biotechnology. Where possible, comparisons are made between the use of these technologies in the United States and other countries.

Artificial Intelligence (AI)

A core objective of AI research and technologies is to automate or replicate human learning and cognition (EOP/NSTC 2016). AI technologies are rapidly integrating machine learning with increasingly available data, and these changes are predicted to have profound implications for the economy and society, with influences on both the production and characteristics of a wide range of products and services—and also on the nature of work (Cockburn, Henderson, and Stern 2018; WIPO 2019). These rapid changes are widely expected to have significant and long-term economic and technological effects on society, including sectors and occupations not historically impacted by technology.

AI research areas and technologies include machine learning, autonomous robotics and vehicles, computable statistics, computer vision, language processing, virtual agents, and neural networks (Furman and Seamans 2018). The expanded use of machine learning and other AI technologies has increased the demand for high-performance computing to improve the velocity and efficiency of AI systems, including training of multitasking AI models. In addition to supporting development of AI, supercomputers are also increasingly using AI to help researchers make discoveries faster. Through better ways of analyzing the present and predicting the future, AI and supercomputing capabilities have the potential to provide solutions for many societal challenges and to facilitate advances in many fields (see sidebar **Trends in High-Performance Computing**).

Although the application of AI has the potential to enhance productivity across many fields and, ultimately, to improve economic welfare for many, AI also has the potential to exacerbate already existing inequalities in the United States. AI innovations result in pronounced advantages for individuals and organizations that can capitalize on this technology and in disadvantages for individuals and organizations who lack the necessary technological skills to harness it effectively. This creates a *digital divide* between those that have AI and those that do not (Carter, Liu, and Cantrell 2020). For example, some firms may be better placed than others to develop or deploy AI. Moreover, if the gains of AI accrue to a small number of superstar innovators or firms with excessive market power, this could produce a divide between innovators and workers—and, thus, further reinforce the potentially negative impact of AI on inequality (Lane and Saint-Martin 2021). AI applications have also been found to perpetuate social biases and stereotypes by finding patterns within data sets that reflect implicit biases and then emphasize and reinforce these biases as global truth. For example, AI-powered advertisements in search engines have been found to display far fewer ads for high-paying executive jobs to women than to men (Howard and Borenstein 2018).

SIDEBAR

Trends in High-Performance Computing

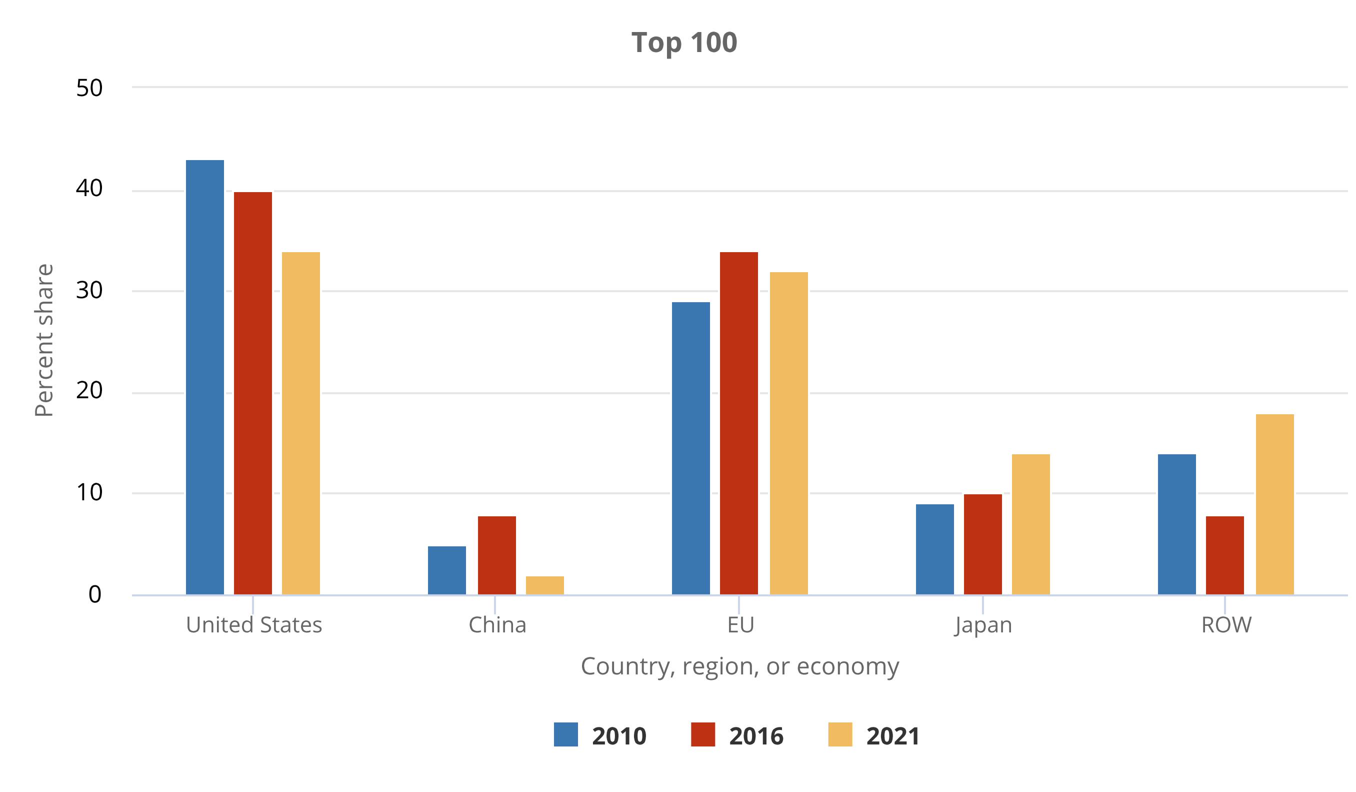
The TOP500, an organization of computer scientists and industry specialists, tracks and reports trends in high-performance computing (**https://www.top500.org/**). It provides a semiannual update on the world's top 500 supercomputers, including information on country of origin, performance, type of application, and technology.

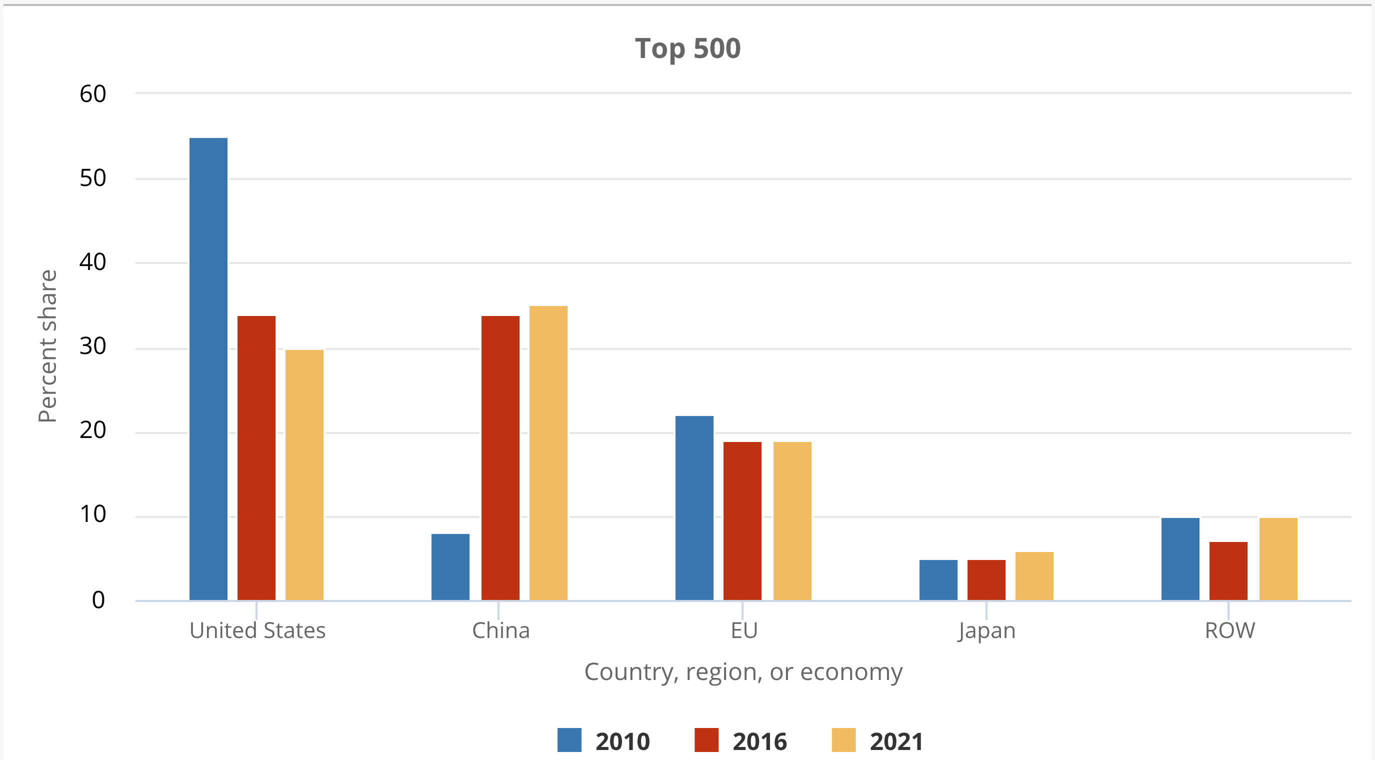
According to its November 2021 update, the Japanese 442-petaflop Fugaku supercomputer remains at the top of the 10 most powerful supercomputers,* followed by two U.S. systems: Summit at the Oak Ridge National Laboratory, and Sierra at Lawrence Livermore National Laboratory. The United States has three more computers in the top 10 list: Selene; Voyager-EUS2; and the National Energy Research Scientific Computing Center's Perlmutter, which recently made this list. China holds two slots in the top 10 list, with the Sunway TaihuLight supercomputer at the National Supercomputing Center in Wuxi ranked fourth, and the Tianhe-2A in the National Supercomputer Center in Guangzhou ranked seventh. The remaining two spots are held by Germany (JUWELS Booster Module) and Italy (HPC5).

China leads overall by number of systems (173 systems in 2021, or a 35% share) and has become dominant in the TOP500 list in a relatively short period of time (**Figure KTI-G**). China's share has increased from 8% in 2010 to 35% in 2021. During the same period, the U.S. share has declined from 55% to 30%.

Figure KTI-G

Top-ranked supercomputers, by region, country, or economy: Selected years, 2010–21





EU = European Union; ROW = rest of world.

Note(s):
EU includes the United Kingdom for comparability with earlier data.

Source(s):
TOP500, November 2010, 2016, and 2021 reports, https://www.top500.org/, accessed 30 November 2021.

Science and Engineering Indicators

Despite its notable achievements, China's dominance is largely limited to less-advanced supercomputers that conduct routine activities, such as running Web-based or back-office applications (Feldman 2017). China has made little progress to increase its presence in the TOP100 list, which consists of the most sophisticated supercomputers used in scientific research, such as processing and simulating quantum mechanics, weather forecasting, climate research, oil and gas exploration, and molecular modeling and physical simulations. The United States dominates the TOP100 list, accounting for a third of these supercomputers (**Figure KTI-G**).

* One petaflop is equivalent to 10^{15} floating-point operations per second.

Investment in AI

Global Trends

AI startups depend heavily on venture capital financing; data on venture capital show emerging areas where investors see potential commercial impacts. Over the past decade, venture capital funding in AI grew rapidly, increasing from around $726 million in 2010 to $54 billion in 2020. In 2020, about 82% of global AI venture capital funding went to startups in the United States and China (Table SKTI-21). Europe also accounted for a significant share of global venture capital funding for AI (9%) although less than the United States (51%) and China (31%).

Flows of venture capital funding in AI to China have been unstable over the past decade when compared to those of the United States. Although venture funding for AI in China surpassed that of the United States in 2017–18, it fell significantly in 2019, from $21 billion to $8 billion. This sharp decline is consistent with an overall decline in venture capital funding in China (for more details, see *2022 Indicators* report, "[2022] Invention, Knowledge Transfer, and Innovation"). In contrast, AI venture funding in the United States grew more consistently during this time, reaching $28 billion in 2020 and accounting for slightly more than half of the global total.

Companies in AI and other emerging technologies also depend on two other forms of financing—private equity, and mergers and acquisitions (M&A)—to continue growing and to commercialize their technology with the goal of becoming a publicly listed company that receives funding from public and institutional investors. Arnold, Rahkovsky, and Huang (2020) constructed a data set to capture total earlier-stage investment in AI firms—venture capital, private equity, and M&A. These data provide a rough estimate of the total amount of financing into AI firms.[13]

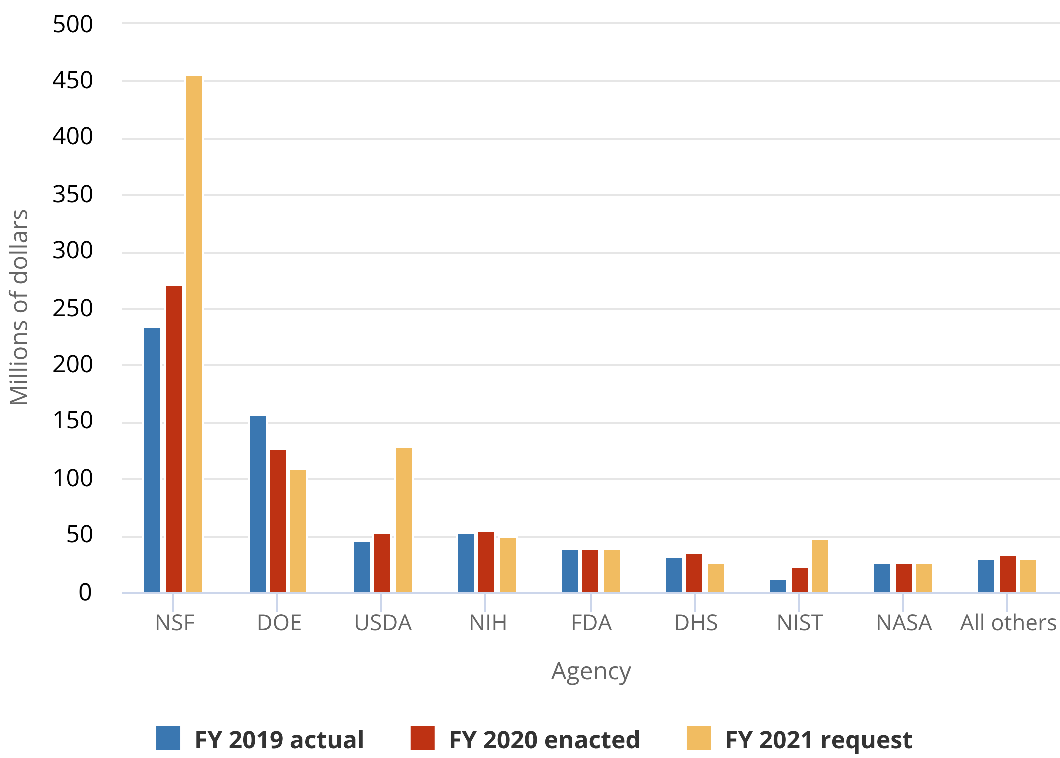
According to these data, combined worldwide investment in venture capital, private equity, and M&A more than doubled from $28 billion in 2015 to $74 billion in 2019. The United States attracted more than half of this investment at $47 billion (64% of the global share). China was the second-largest recipient of this funding, receiving $7 billion, half its level in 2018 and far below the United States. U.S. companies received more AI investment and are most active in AI applications of business services and analytics, general purpose applications, and medicine and life sciences. In contrast, Chinese companies are active in areas such as security and biometrics (including facial recognition), arts and leisure (including personal social media platforms), and transportation (Arnold, Rahkovsky, and Huang 2020).

U.S. Trends

The U.S. federal government invested an estimated $1.1 billion in funding nonmilitary AI in FY 2020, 15% higher compared to FY 2019, according to the Networking and Information Technology Research and Development (NITRD), a federal program that coordinates the activities of multiple agencies to tackle multidisciplinary, multitechnology, and multisector R&D needs (NITRD 2021). The $1.1 billion in AI R&D in FY 2020 consists of $670 million in R&D that is explicitly identified as directly applicable to AI and of $350 million in R&D that is related to AI but may have a primary classification in a non-AI technology. Four federal departments and agencies—the National Science Foundation, the Department of Energy (DOE), the Department of Agriculture (USDA), and National Institutes of Health (NIH)—accounted collectively for more than three-quarters of the direct AI funding in FYs 2019–20 (**Figure KTI-21**). These estimates do not include substantial R&D investments in military and intelligence applications, which are not disclosed to the public.

Figure KTI-21

U.S. federal R&D in AI, by selected agency: FYs 2019–21



AI = artificial intelligence; DHS = Department of Homeland Security; DOE = Department of Energy; FDA = Food and Drug Administration; NASA = National Aeronautics and Space Administration; NIH = National Institutes of Health; NIST = National Institute of Standards and Technology; NSF = National Science Foundation; USDA = Department of Agriculture.

Note(s):
NSF FY 2020 budget includes $5.6 million in supplemental funding.

Source(s):
Networking and Information Technology Research and Development Program (NITRD), *Supplement to the President's FY 2021 Budget* (2020), https://trumpwhitehouse.archives.gov/wp-content/uploads/2017/12/FY2021-NITRD-Supplement.pdf, accessed 15 October 2021.

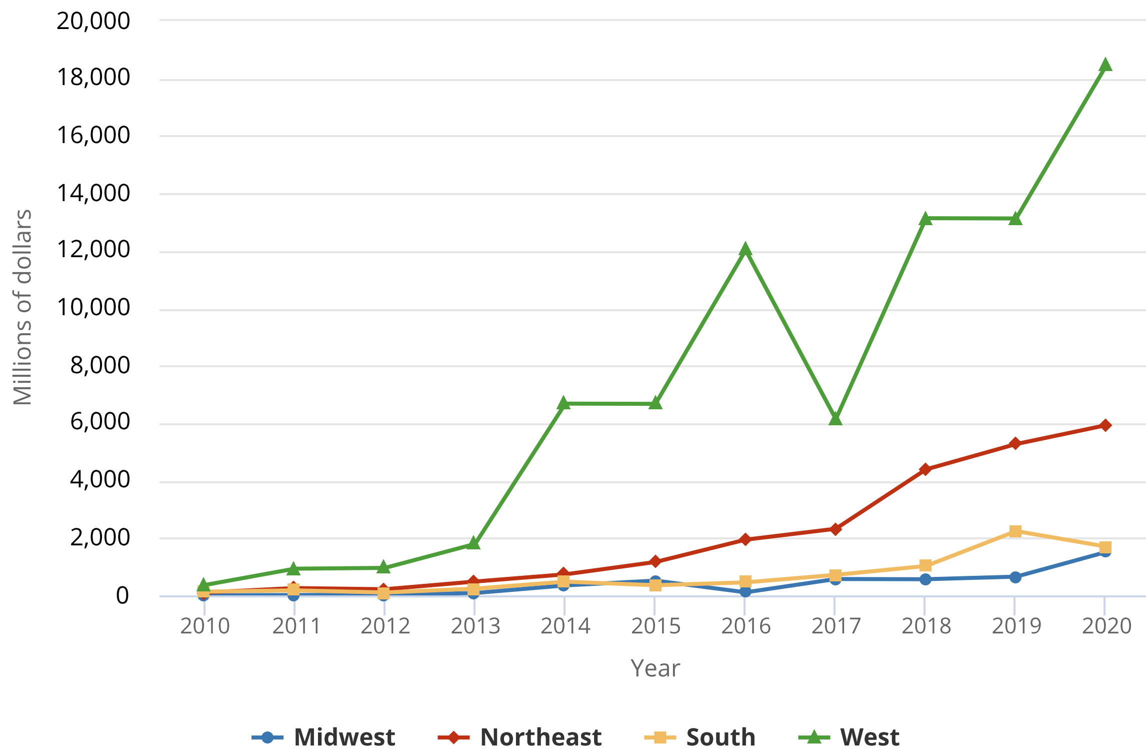
Science and Engineering Indicators

In addition to federal funding, venture capital remains critically important for AI-related firms in the United States. Between 2010 and 2020, total venture investments in U.S. AI startups grew from $598.1 million to $27.6 billion, with a compound annual growth rate of 47% (Table SKTI-22). While growth in AI venture funding has been ubiquitous throughout the United States, different regions and states have seen varying levels of growth over the past several years.

The concentration and growth of venture capital financing in AI across Census regions has been uneven over the past decade. The Western United States continues to attract the vast majority of AI venture capital financing in the United States (**Figure KTI-22**; Table SKTI-22). Of the more than $115 billion in AI venture funding raised in the United States between 2010 and 2020, $80.3 billion (70%) flowed to the West—in particular, to California ($71.8 billion). The Northeast received the next-highest portion of total U.S. AI venture capital ($22.8 billion, or 20%), with New York ($11.9 billion) and Massachusetts ($8.2 billion) receiving the most in the region. The dominance of the Northeast and the West in attracting venture capital funding is consistent with these regions producing the most KTI output. Smaller amounts flowed to states in the South ($7.6 billion, or 7%) and the Midwest ($4.4 billion, or 4%).

Figure KTI-22

AI-related venture capital funding, by U.S. region: 2010–20



AI = artificial intelligence.

Source(s):
PitchBook, venture capital and private equity database, accessed 27 September 2021.

Science and Engineering Indicators

While the Northeast and the West attracted the most venture capital funding in AI on a per-dollar basis, this investment grew the most in the Midwest from a low starting position between 2010 and 2020. AI-related venture capital in the United States grew, on average, 47% per year, while investments in the West (48%) and the Northeast (50%) grew a few percentage points faster. In the Midwest, however, AI venture investing grew on average 75% per year, exceeding that of the other regions and the nation. Although the South raised more AI venture capital than the Midwest between 2010 and

2020, it grew 29% per year. Because of its comparatively faster growth, the AI venture capital in the Midwest is catching up to the South. For example, the Midwest and the South began the decade with significantly different levels of financing ($5.6 million and $131.3 million, respectively), but by 2020, both regions were attracting similar amounts ($1.5 billion and $1.7 billion, respectively). Additionally, unlike the composition of investment growth in the West and the Northeast, where investments are concentrated in one or two states, both the Midwest and the South see a greater number of states attracting notable levels of funding. States like Illinois, Ohio, and Minnesota account for a larger share of growth in the Midwest, while states like Texas, Virginia, Georgia, and Florida fueled growth in the South.

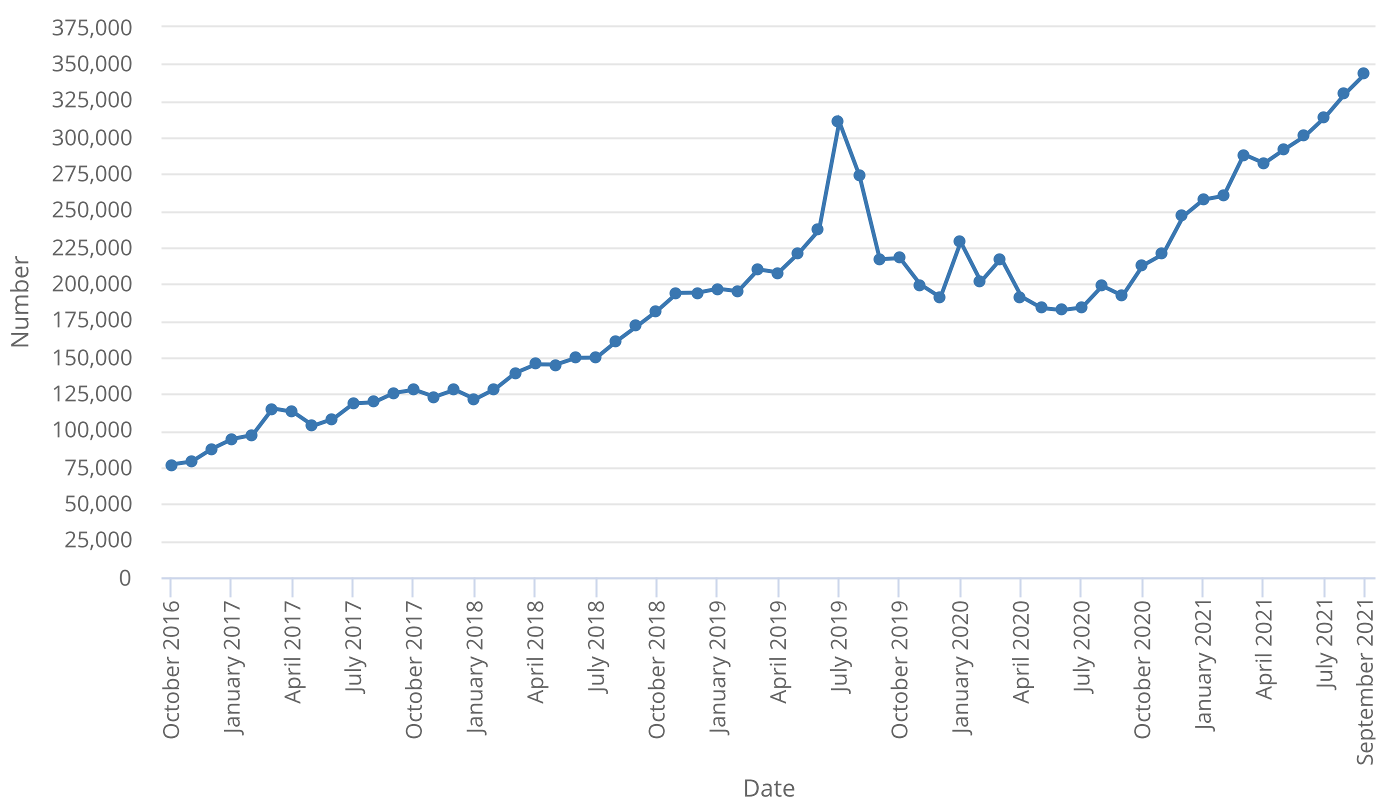
Demand for Workers with AI-Related Skills in the United States

In this section, AI-related job postings between October 2016 and September 2021 serve as proxy for demand for AI-related skills in the U.S. workforce. Emsi Burning Glass, the source of job postings used in this analysis, identifies the top 25 most common skills related to the AI workforce.[14] Between October 2016 and September 2021, approximately 3.7 million unique jobs were advertised in all 50 states and the District of Columbia that referenced at least 1 of the 25 AI-related skills identified. Of the 188 million job postings in the United States during this time, postings with AI-related skills represent 2% of all postings.

Job postings with AI-related skills grew consistently over the last few years (**Figure KTI-23**). Between October 2016 and September 2021, these postings grew at an average monthly rate of about 3%. Notably, growth in demand for AI-related skills accelerated during the COVID-19 pandemic. AI-related job postings prior to the pandemic—that is, between September 2016 and March 2020—grew at an average monthly rate of 3%. While postings fell by 12% at the start of the pandemic (between March 2020 and April 2020), AI-related job postings since April 2020 have grown at an average rate of about 3.7%.[15]

Figure KTI-23

Total AI-related job postings in the United States: October 2016–September 2021



AI = artificial intelligence.

Note(s):
Monthly data may include jobs that were posted in one month and subsequently removed, then re-posted in another month. This may result in a larger total number of jobs posted by month than the total number of jobs posted by geography.

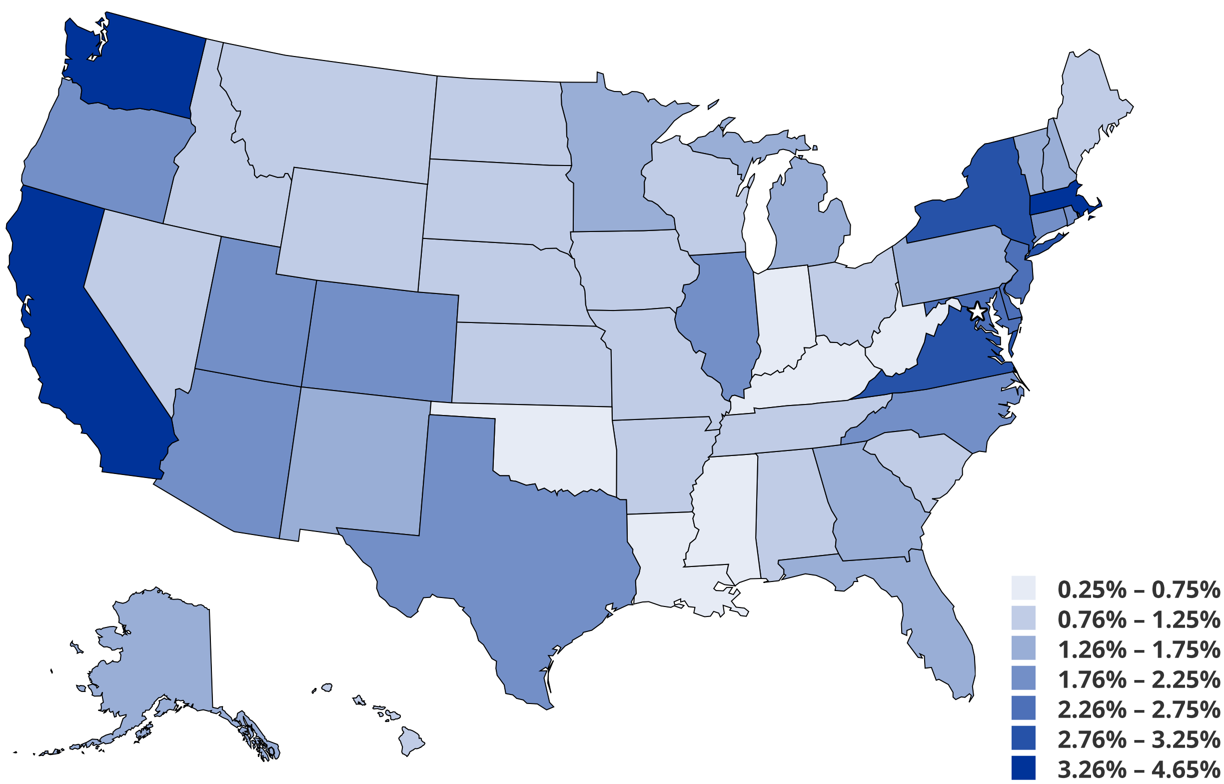
Source(s):
Emsi Burning Glass, Job Posting Analytics, accessed 15 October 2021.

Science and Engineering Indicators

Analysis of demand for AI-related skills at the geographic level demonstrates concentration of AI-related skills in certain regions of the United States. Coastal states account for a significant share of AI-related job postings during the observed period (**Figure KTI-24**; Table SKTI-23). Between October 2016 and September 2021, the District of Columbia (5%), Washington (4%), and California (4%) had the largest percentage of AI-related job postings as a share of all job postings within their jurisdictions. Six of the remaining 7 states in the top 10 fall along the East Coast: Massachusetts (3%), New York (3%), Virginia (3%), New Jersey (2%), Maryland (2%), and Delaware (2%). Colorado (2%) is the only inland state to place in the top 10 states that have experienced the most intense demand for AI-related skills.

Figure KTI-24

Unique AI-related job postings as a share of all unique job postings, by state: October 2016–September 2021



AI = artificial intelligence.

Note(s):
See Table SKTI-23 for a detailed breakdown of total unique job postings and total unique AI-related job postings by U.S. state. Job postings per 100,000 people are based on the U.S. Census 2019 population totals by state.

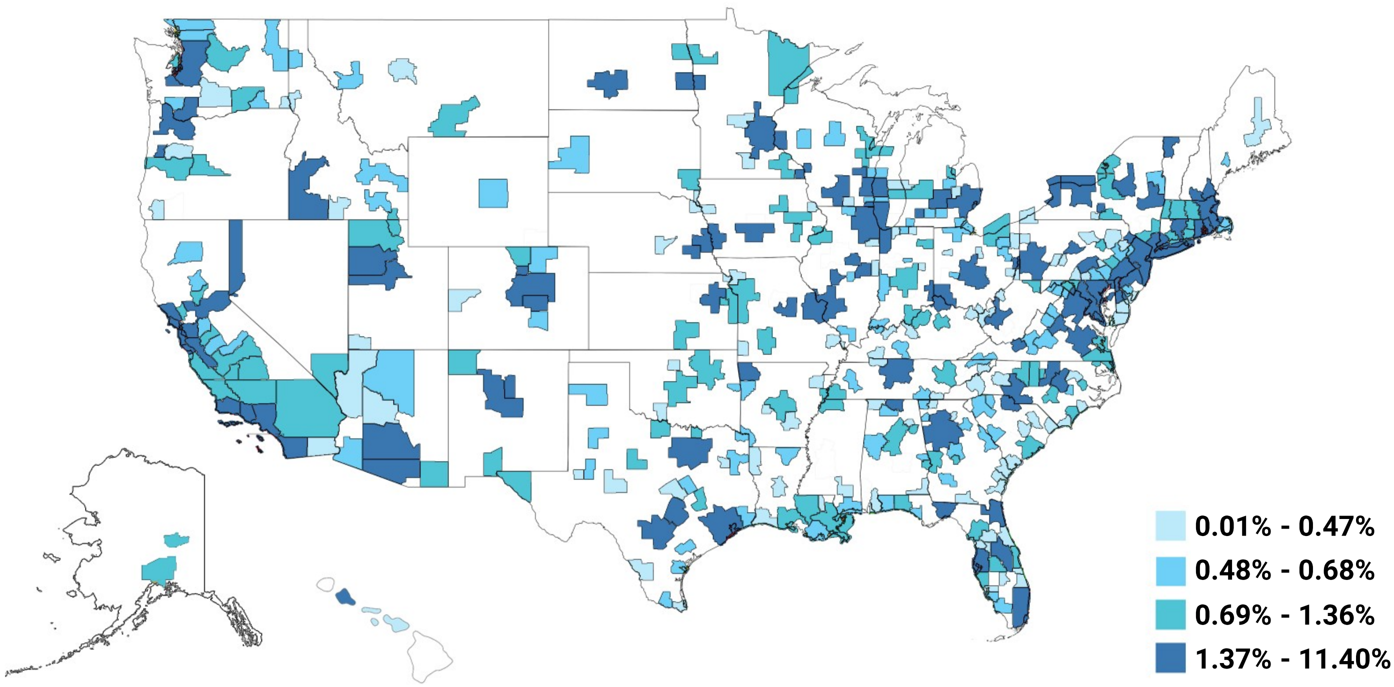
Source(s):
Emsi Burning Glass, Job Posting Analytics, accessed 15 October 2021.

Science and Engineering Indicators

Metropolitan area trends in job postings for those with AI-related skills generally reflect the presence of "superstar" metropolitan statistical areas (MSAs) that see significant demand for a workforce with specialized technical capabilities.[16] Among the 157 million jobs posted between October 2016 and September 2021 in the 384 MSAs defined by the Census Bureau, AI-related job postings account for 3.5 million (2%) of all postings (**Figure KTI-25**). Seven metro areas have twice the rate of AI-related job postings as the United States, indicating a high concentration of AI-related job postings in a small number of MSAs: San Jose-Sunnyvale-Santa Clara, CA (11%); San Francisco-Oakland-Berkeley, CA (7%); Seattle-Tacoma-Bellevue, WA (6%); Trenton-Princeton, NJ (5%); Boulder, CO (5%); Washington-Arlington-Alexandria, DC-VA-MD-WV (4%); and Austin-Round Rock-Georgetown, TX (4%).

Figure KTI-25

Unique AI-related job postings as a share of all unique job postings, by selected metropolitan statistical areas: October 2016–September 2021



AI = artificial intelligence; MSA = metropolitan statistical area.

Note(s):
The data represented in the table indicate the top 20 MSAs with job postings related to AI. The map represents all AI job postings within the 384 MSAs in the United States. Job postings per 100,000 people are based on the 2019 MSA Census Population numbers.

Source(s):
Emsi Burning Glass, Job Posting Analytics, accessed 15 October 2021.

Science and Engineering Indicators

In addition to concentration, the relative intensity of AI-related job postings in the U.S. metropolitan areas is measured as the number of AI-related job postings per 100,000 population in each metropolitan area relative to a metropolitan area's population size as of the 2019 ACS. Many of the MSAs with the highest concentration of AI-related job postings also have the greatest intensity of these postings adjusted for population. For example, San Jose-Sunnyvale-Santa Clara, CA, and

San Francisco-Oakland-Berkeley, CA, are the most concentrated and have the largest relative intensity (9,660 and 5,188 per 100,000, respectively). However, other highly concentrated metropolitan areas like Austin-Round Rock-Georgetown, TX (4.1%), have lower relative intensity of AI-related job postings (2,749 per 100,000). In contrast, Carson City, NV, has greater intensity (3,879 per 100,000), despite lower concentration (3.5%).

AI Patents

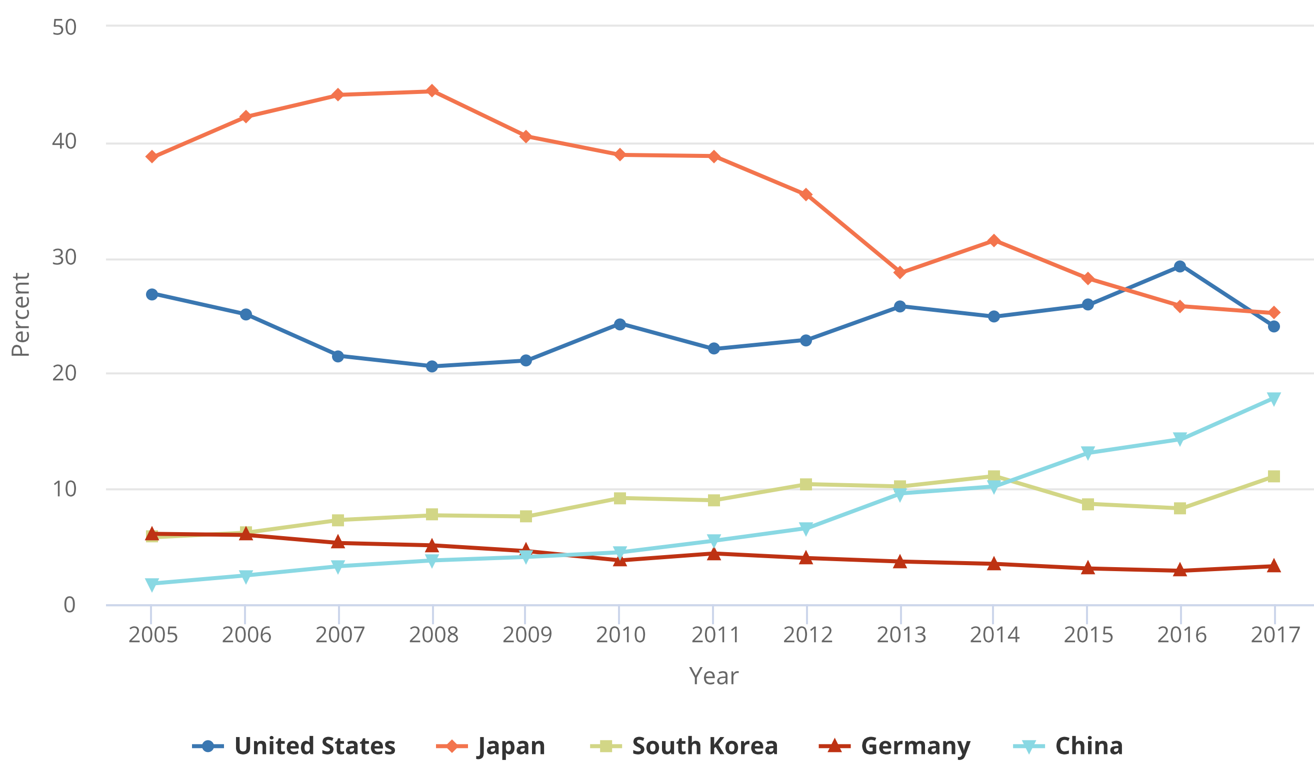
AI capabilities include patenting and innovation activities and publications related to AI technologies. This section analyzes trends in patenting activities across countries and over time. Trends in patent application filings and publications help to show the increasing prevalence of a technology in an economy over time. A detailed discussion of publications related to AI can be found in the *2020 Indicators* report "**Production and Trade of Knowledge- and Technology-Intensive Industries**."

The United States Patent and Trademark Office (USPTO) collects data on invention filings for AI-related technologies. A 2020 paper released by the USPTO finds that, between 2002 and 2018, annual filings for AI patent applications increased by more than 100% in the United States, while the share of all patent applications containing AI grew from 9% to 16% (Toole et al. 2020). These data indicate a growing intensity of AI in the U.S. economy, with more inventions filed in the United States making use of the technology.

The U.S. share of AI-related patent families filed within at least 1 of the top 5 global intellectual property offices (USPTO, European Patent Office, Japan Patent Office, Korean Intellectual Property Office, National Intellectual Property Administration of the People's Republic of China) has remained relatively steady over time (**Figure KTI-26**). Although falling from 26.9% in 2005 to 24.0% in 2017, the U.S. share has recovered slightly from the smaller shares seen between 2007 and 2012. Meanwhile, China and South Korea have both increased their shares of global patents filed for AI-related technologies, from 1.8% to 17.9% and 5.8% to 11.1%, respectively.

Figure KTI-26

Country share of AI-related patents, by top 5 countries: 2005–17



AI = artificial intelligence.

Note(s):
Patents are based on IP5 patent families, and percentages are based on fractional counts. IP5 is a forum of the 5 largest intellectual property offices in the world. The IP5 members are the European Patent Office, Japan Patent Office, Korean Intellectual Property Office, National Intellectual Property Administration of the People's Republic of China, and United States Patent and Trademark Office.

Source(s):
Organisation for Economic Co-operation and Development, STI Micro-data Lab, Intellectual Property Database, https://www.oecd.org/sti/intellectual-property-statistics-and-analysis.htm, accessed 8 October 2021.

Science and Engineering Indicators

AI Adoption in Businesses

As an enabling technology, or general-purpose technology (GPT), AI is expected to contribute to increased productivity for businesses, leading to increased long-run economic growth (Aghion, Jones, and Jones 2017). Much research has been done on the impact of GPTs—including AI—on the U.S. economy (Gordon 2015; Brynjolfsson, Rock, and Syverson 2017). Until recently, the available data suggested that AI and other GPTs have not contributed to increased productivity, despite the new technologies and investment they brought. The leading explanation for this paradox is that there is a delay between the emergence of a GPT and its contribution to growth because other complementary intangible investments—such as data sets, firm-specific human capital, and new business processes—are also required (Brynjolfsson, Rock, and Syverson 2017). This debate has been difficult to resolve because comprehensive business sector data on the diffusion and impact of AI and other technologies have been limited to surveys focused on a single sector or focused primarily on large enterprises.

A new technology module of the **Annual Business Survey** (ABS)—developed in partnership between the Census Bureau and NCSES—collects data on the adoption and use of several advanced business technologies from a large, nationally representative sample of 850,000 smaller and larger firms in private, nonfarm sectors of the economy. Advanced business technologies include AI-related technologies like guided vehicles, machine learning, machine vision, natural language processing, and voice recognition software. Using data from this new ABS module, Zolas et al. (2020) found that adoption rates for advanced business technologies in the United States were generally low—and were significantly lower than levels reported in earlier surveys.[17]

Importantly, although nearly all firms use some form of digital information, and most use some kind of cloud service, only 10.3% of firms in 2017 adopted at least one of the advanced business technologies, such as AI. Adoption of these advanced business technologies is skewed heavily toward larger firms (i.e., those with more than 5,000 employees), with more than 50% of them making use of advanced business technologies that embody AI. Adoption rates also vary across sectors, with use of advanced business technologies concentrated in industries such as manufacturing and IT. In contrast, the service sector shows lower levels of advanced business technology adoption, including management and financial services. Somewhat surprisingly, transportation and warehousing also show low levels of adoption, which may reflect the greater role of smaller firms in this sector (Zolas et al. 2020).

Research suggests that the adoption of advanced business technologies impacted the productivity of U.S. businesses. For example, Andrews, Criscuolo, and Gal (2016) and Autor et al. (2017) agree that macroeconomic indicators show a slowdown in U.S. business productivity over the last two decades. However, the authors argue that these indicators obscure a significant divergence in productivity across firms. Firms operating at the "frontier"—which are often larger enterprises—have witnessed an increase in productivity, while other firms have seen lagging productivity performance. The rise of superstar firms is consistent with the ABS data on AI adoption. The data suggest a self-reinforcing cycle in which large firms are better able to adopt GPTs, leading to increased firm-level productivity. Technology adoption, as measured by the technology module of the ABS, is associated with increased productivity, as measured by the innovation module of the ABS (Zolas et al. 2020). The implication is that GPTs, including AI, have an especially strong impact on the growth of large enterprises and are a source of increased industry concentration by increasing divergence between superstar firms and the rest.

Biotechnology

Although there is no consensus on defining biotechnology, it can be broadly defined as "the broad application of science and technology to living organisms, as well as parts, products and models thereof, to alter living or non-living materials for the production of knowledge, goods and services" (OECD 2013:156).[18] Modern biotechnology developed as a science with enormous potential for human welfare in areas ranging from food processing to human health and environmental protection. One of the major areas in biotechnology is medicine. This is the field in which most of the R&D is taking place, and several breakthroughs have been made. This area includes medical applications, such as utilizing organisms for the production of novel drugs or employing stem cells to replace or regenerate injured tissues and possibly regenerate whole organs. Another major area is industrial biotechnology, which includes modern application of biotechnology for sustainable processing and production of chemical products, materials, and fuels (Erickson and Winters 2012). Use of biotechnology to substitute existing processes makes industrial sectors like chemicals and pharmaceuticals, pulp and paper, textiles, energy, and materials and polymers more efficient and environmentally friendly, contributing to industrial sustainability in various ways. A third major area is agricultural biotechnology. With the aid of rDNA technology, it has now become possible to produce transgenic plants with desirable genes, such as herbicide resistance, disease resistance, and increased shelf life (USDA/ERS 2020).

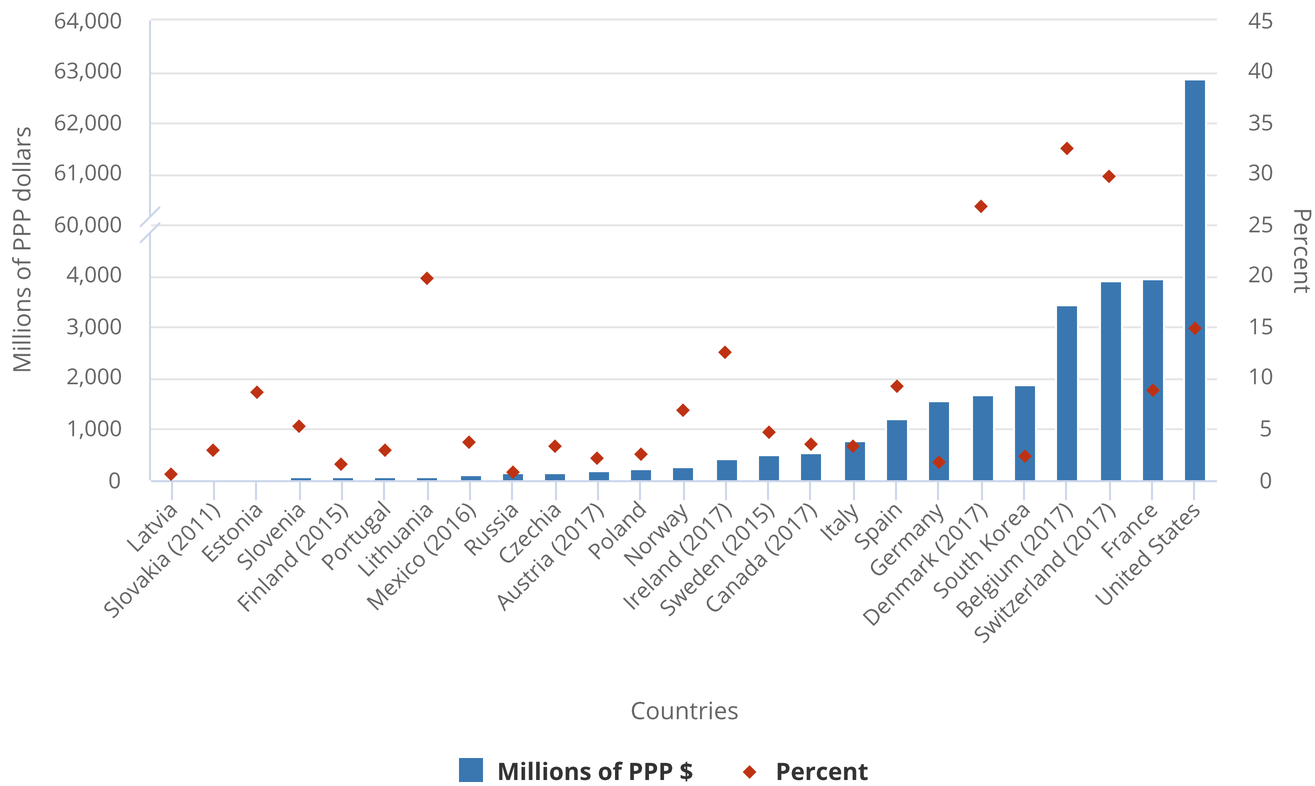
Investment in Biotechnology

Global Trends

According to OECD (2021a), the United States performs the most business sector biotechnology R&D ($63 billion, or 70%) among the 25 countries for which data are available (**Figure KTI-27**). This is almost 16 times that of France ($3.9 billion), the next largest. Although the United States performs the most biotechnology R&D, its share of total domestic R&D and its R&D intensity—that is, biotechnology R&D as percentage of industry value added—is below that of other countries. In terms of share of total domestic R&D to biotechnology, the United States ranks fifth (15%) among the 25 countries, well below the 27%–32% shares reported in Switzerland, Belgium, and Denmark. Similarly, the United States (0.5) ranks fourth for biotechnology R&D intensity, while higher biotechnology R&D intensity is reported in Belgium (1.0), Switzerland (1.0), and Denmark (0.8) (OECD 2021a).

Figure KTI-27

Biotechnology R&D expenditures and biotechnology R&D expenditures as a share of total domestic R&D for reporting OECD countries, by country: 2018 or latest year available



OECD = Organisation for Economic Co-operation and Development; PPP = purchasing power parity.

Source(s):
Organisation for Economic Co-operation and Development, Key Biotechnology Indicators, http://oe.cd/kbi, and Main Science and Technology Indicators Database, www.oecd.org/sti/msti.htm, accessed 8 October 2020.

Science and Engineering Indicators

Although the OECD does not collect biotechnology data on China, other evidence suggests that China has committed resources to expand its presence in biotechnology. President Xi Jinping has made China's leadership in this sector a core priority through the *Made in China 2025* strategy (Huggett 2019). According to the World Health Organization (2017), the Chinese government is targeting the domestic pharmaceutical industry to invest 5% of revenues in R&D, but that target is not yet reached. To put this into context, U.S. pharmaceutical industries invest roughly 11% of their revenues in R&D, which is much greater than the target set by the Chinese government (see forthcoming *Indicators 2022* report, "[2022] Research and Development: U.S. Trends and International Comparisons"). Nevertheless, some estimates show that annual R&D expenditures by Chinese pharmaceutical firms, the foundation of the biotechnology sector, rose from some 39 billion renminbi (RMB) in 2014 ($5.5 billion in U.S. dollars) to over 53 billion RMB ($7.5 billion in U.S. dollars) by 2017. Expenditures on new product development among these firms, an important indicator of future growth potential, increased from just over 40 billion RMB ($5.6 billion in U.S. dollars) to almost 60 billion RMB ($8.4 billion in U.S. dollars) (Moore 2020). Overall, highly innovative drugs still originate from international companies, and Chinese manufacturers excel in generics (e.g., biosimilars) and traditional Chinese medicine (Schmid and Xiong 2021).

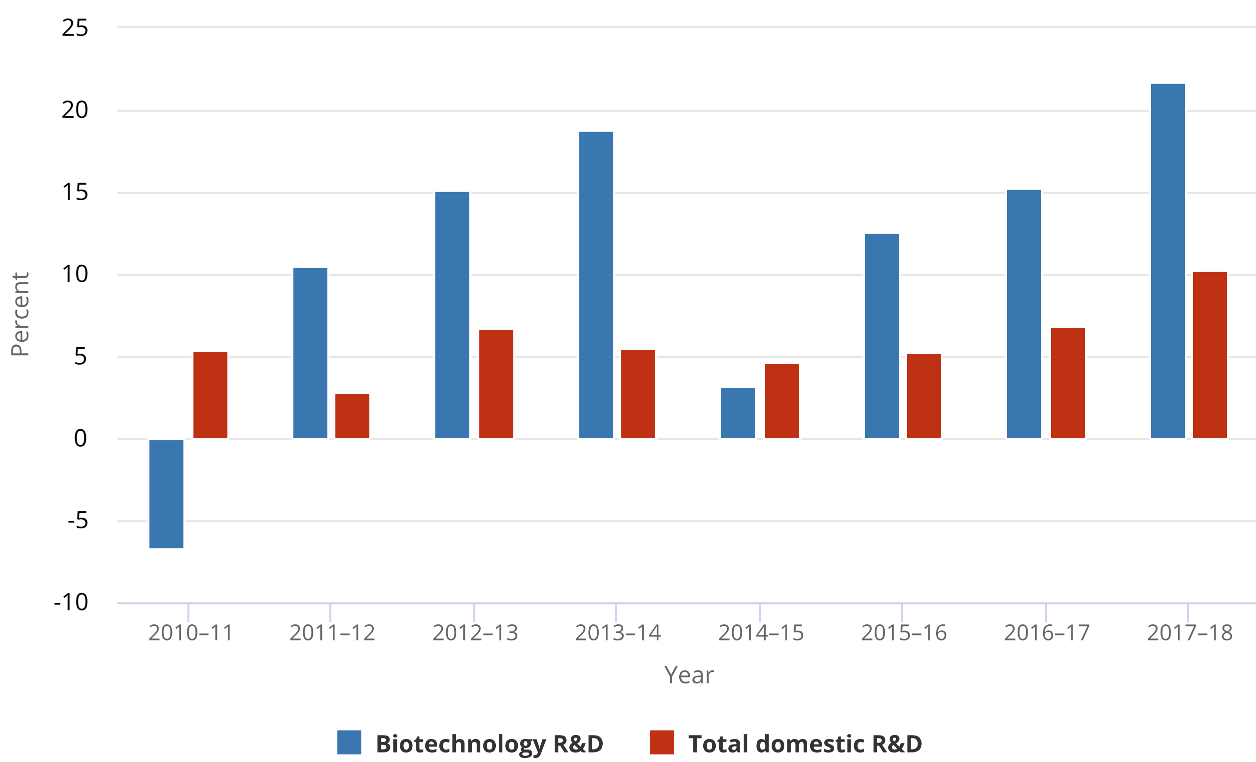
Venture capital data also show China's increasing presence in biotechnology. According to data from PitchBook, global venture capital investment in biotechnology was $44.0 billion in 2020 (Table SKTI-24).[19] The United States is the largest destination, receiving more than 60% of total investment, and is followed by China (19% global share) and Europe (15% global share). The amount of investment has increased significantly over the last decade, growing from $4.5 billion in 2010 to $44.0 billion in 2020. China's investment expanded rapidly from 2015 to 2020, rising from less than $1.0 billion to $8.3 billion. Although investment continued to grow in the United States, its global share fell slightly from 68% to 67% due to comparatively faster growth by China.

U.S. Trends

NCSES collects data on U.S. business spending on biotechnology R&D performance through the Business Research and Development Survey (BRDS).[20] According to these data, domestic business R&D performance on biotechnology was $49 billion in 2018. U.S. business R&D performance on biotechnology was seven times that of business R&D performance on AI, which was $7 billion in 2018 (NCSES ***BRDS 2018***: **Table 1**). Biotechnology business R&D performance increased an average of 11% from 2010 to 2018, whereas total domestic R&D performance increased an average of 6% (**Figure KTI-28**). The faster growth of biotechnology business R&D performance compared to the total has led to an increase in the proportion of total domestic R&D performance in biotechnology from 10% to 14% between 2010 to 2018. More recently, growth in biotechnology R&D has outpaced total domestic R&D performance. This indicates an increasing research focus on biotechnology in the United States.

Figure KTI-28

Annual change in biotechnology R&D performance and total domestic R&D performance: 2010–18



Source(s):
National Center for Science and Engineering Statistics and U.S. Census Bureau, Business R&D and Innovation Survey, 2010–16; National Center for Science and Engineering Statistics, Business R&D Survey, 2017–18.

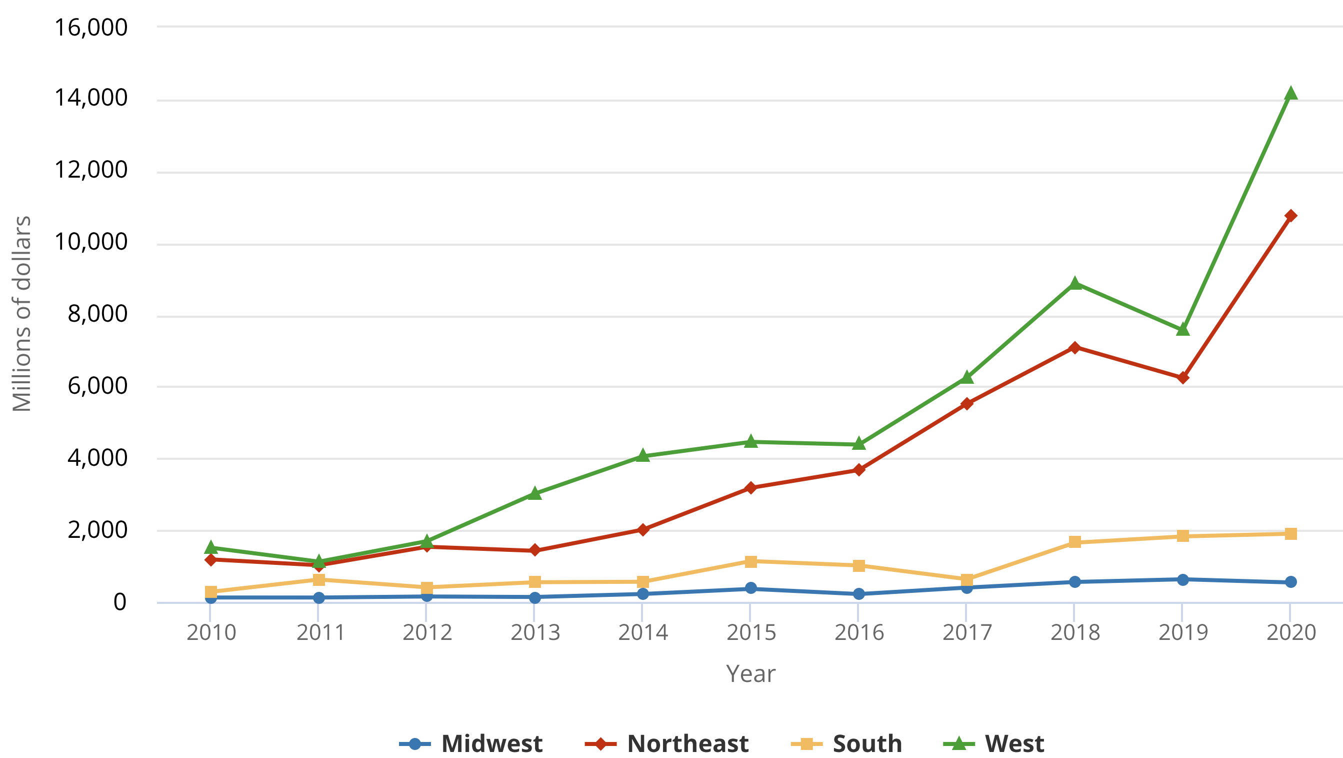
Science and Engineering Indicators

According to the BRDS (NCSES ***BRDS 2018***: **Table 20**), most biotechnology R&D in the U.S. business sector is performed in manufacturing by large companies, and it is paid for by the companies' own funds. Pharmaceutical and medicine manufacturers (73%) perform the most domestic R&D on biotechnology, followed by scientific research and development services (13%), computer and electronic products manufacturing (4%), miscellaneous manufacturing (4%) (e.g., medical equipment and supplies, games, office supplies, slot machines), and the food industry (2%). Most companies that engage in biotechnology R&D employ fewer than 250 employees (82%); however, companies with 250 or more employees performed $51 billion, or 82% of all biotechnology R&D. Of these companies, 78% paid for biotechnology R&D using their own funds rather than funds from another entity (i.e., another company or the federal government).

Data from PitchBook show the flow of venture capital financing within the United States. U.S. venture capital investments in biotechnology increased from $3.1 billion in 2010 to $27.4 billion in 2020, accumulating $115 billion during this period. The majority of this funding went to states in the West Census region ($57.1 billion, or 50%) and Northeast ($43.6 billion, or 38%) (**Figure KTI-29**; Table SKTI-25). California ($49.9 billion) attracted 88% of venture capital in the West, and Massachusetts ($32.0 billion) attracted 73% in the Northeast; these two states and their regions thus attracted most venture capital in the United States overall during this period. Smaller amounts flowed to states in the South (9% of total) and in the Midwest (3% of total), and funding was distributed more evenly among the states within each of these regions.

Figure KTI-29

Biotechnology-related venture capital funding, by U.S. region: 2010–20



Source(s):
PitchBook, venture capital and private equity database, accessed 27 September 2021.

Science and Engineering Indicators

Consistent with previous analysis, biotechnology venture capital grew the most in regions that have historically attracted more funding.[21] The West and the Northeast attracted the highest levels of funding and grew the fastest at 25% per year between 2010 and 2020. The growth in these regions was led by California and Massachusetts. As a result, the Northeast increased its share of U.S. total venture capital financing in biotechnology from 33% in 2010–15 to 40% in 2016–20, and the West's share has been relatively constant since 2015 at 47%–52%.

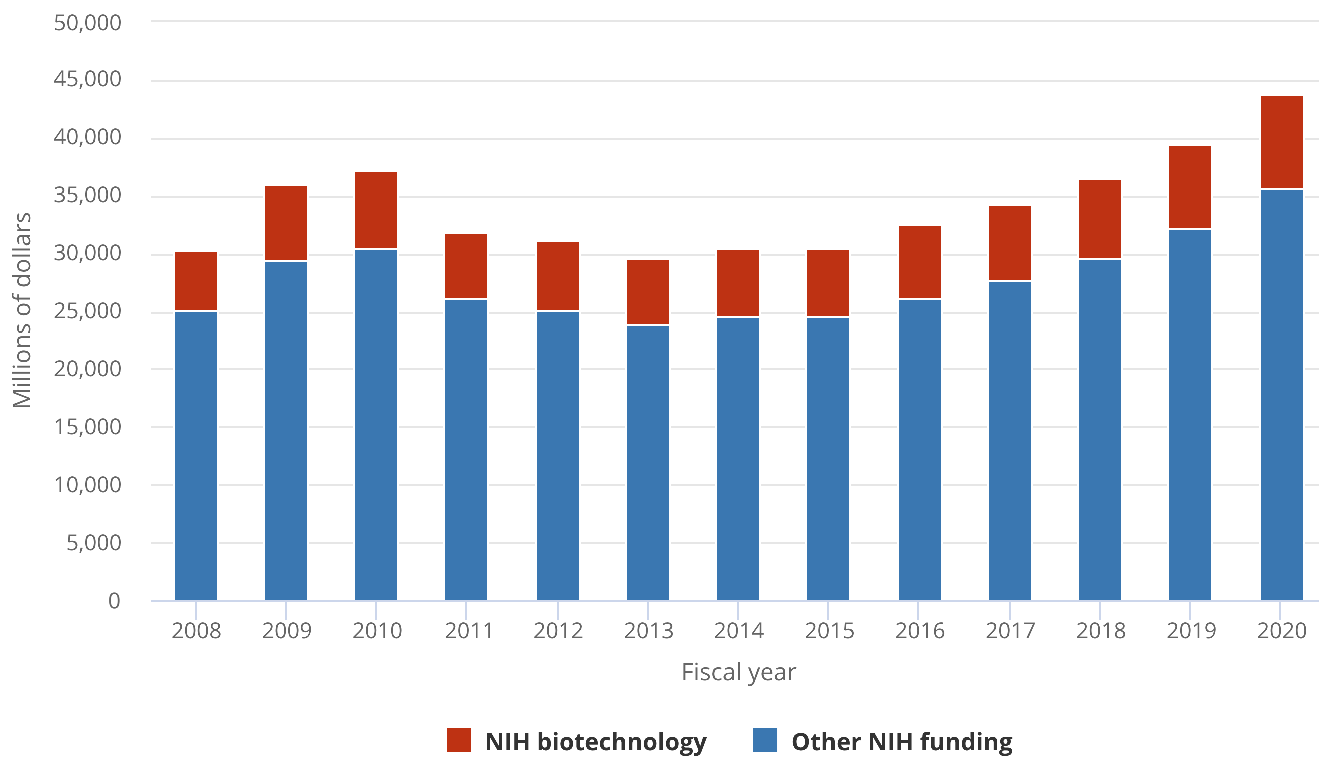
Concentration decreased in the South and the Midwest as these regions grew at slower rates and had the lowest levels of funding compared to the Northeast and the West. Between 2010 and 2020, the South grew at 21% per year, while the Midwest grew at 16%. Between 2010 and 2015, the South represented about 12% of all biotechnology venture capital investment in the United States, but this share fell to 8% between 2016 and 2020. The share of biotechnology investments in the Midwest ranged between 2% and 4% during this period.

Analysis of the PitchBook venture capital data for the U.S. biotechnology sector yields a few key similarities with the U.S. AI sector. First, venture financing for both enabling technologies is highly concentrated in the West and the Northeast—in particular, in California and Massachusetts—on a per-dollar and percentage-share basis. Second, while some regions and sectors, such as the Midwest in AI and the South in biotechnology, are seeing high rates of annual growth, this growth has not been enough to increase the share of these regions' venture investments within the United States overall. Third, in both AI and biotechnology, venture capital investments are more evenly distributed across states in the South and the Midwest, whereas investments in the West and the Northeast are highly concentrated in one or two states. Perhaps most notably, although biotechnology ($3.1 billion in 2010) began the decade with significantly higher rates of investment than AI ($598.1 million), in 2020 both technologies received similar levels of investment—about $27 billion. The increase in AI venture capital investments in the United States has been so rapid that, between 2010 and 2020, biotechnology and AI firms in the United States received similar levels of venture funding—roughly $115 billion.

The federal government is also an important source of funding for biotechnology R&D. NIH funds a substantial amount of biotechnology R&D.[22] NIH obligated about $8 billion on biotechnology grants or contracts in 2020, which is 19% of overall NIH obligations. NIH obligations on biotechnology research grew 4% per year since 2008, 1 percentage point more than total NIH (3%) (**Figure KTI-30**). Excluding NIH intramural spending obligations, in 2020, organizations in California, Washington, and Massachusetts were awarded the most NIH grants or contracts on biotechnology, a pattern similar to the venture capital financing across states.

Figure KTI-30

National Institutes of Health obligations for biotechnology and other funding: FYs 2008–20



NIH = National Institutes of Health.

Note(s):
Obligated amounts reflect grants or contracts administered by NIH in total and for NIH spending category Biotechnology.

Source(s):
National Institutes of Health, RePORTER database, version 2020.9, https://reporter.nih.gov/, accessed 10 November 2021.

Science and Engineering Indicators

Demand for Workers with Biotechnology-Related Skills in the United States

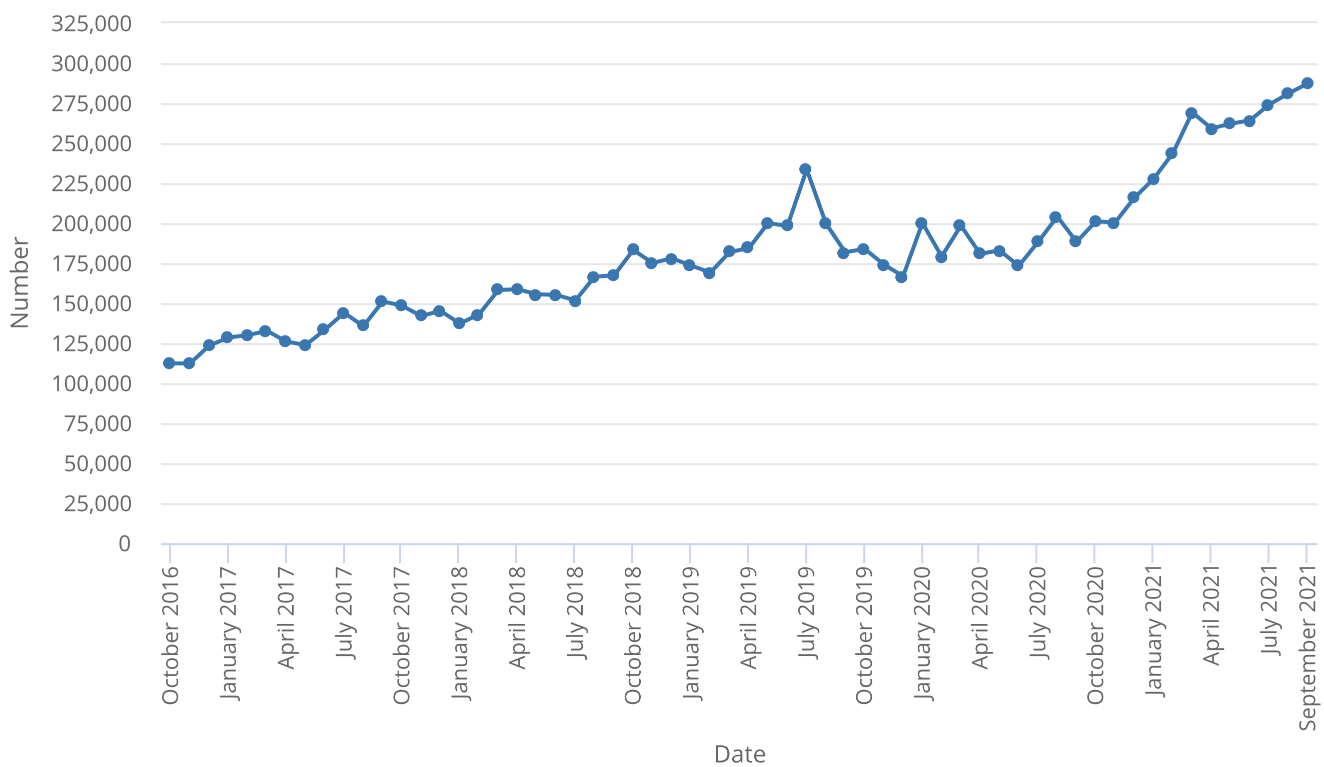
In addition to investors, the biotechnology sector has attracted attention from workers and employers alike. According to employment numbers provided by the U.S. Bureau of Labor Statistics (BLS), demand for workers in R&D, life sciences, and engineering will increase between 2019 and 2029. This is likely driven in part by pandemic-induced increased demand for workers in these sectors. BLS estimates between 55,000 and 748,300 jobs, in moderate or strong impact scenarios, could be added to these sectors from 2019 to 2029 (Ice, Rieley, and Rinde 2021). In the pharmaceutical and medicine manufacturing industry, BLS estimates between 364,000 to 365,000 jobs during the same time period, respective to moderate and strong impact scenarios.

This section identifies biotechnology-related job postings using the top 25 most common biotechnology-related skills defined by Emsi Burning Glass.[23] This methodology yields a total of 3.7 million biotechnology-related job postings between October 2016 and September 2021. During this period, a total of 189.3 million jobs were advertised in the United States, with biotechnology-related postings accounting for 1.9% of all job postings.

Compared to pre-pandemic, biotechnology-related job postings grew at a higher rate since the onset of the pandemic early in 2020 (**Figure KTI-31**). Between October 2016 and March 2020, biotechnology-related job postings increased at an average monthly rate of 1.6%. Despite a temporary decrease in postings between March and April 2020 (-8.9%) during the state shutdowns, between April 2020 and September 2021 biotechnology-related job postings have increased at an average monthly rate of 2.8%.

Figure KTI-31

Total biotechnology-related job postings in the United States: October 2016–September 2021



Note(s):
Monthly data may include jobs that were posted in one month and subsequently removed, then re-posted in another month. This may result in a larger total number of jobs posted by month than the total number of jobs posted by geography.

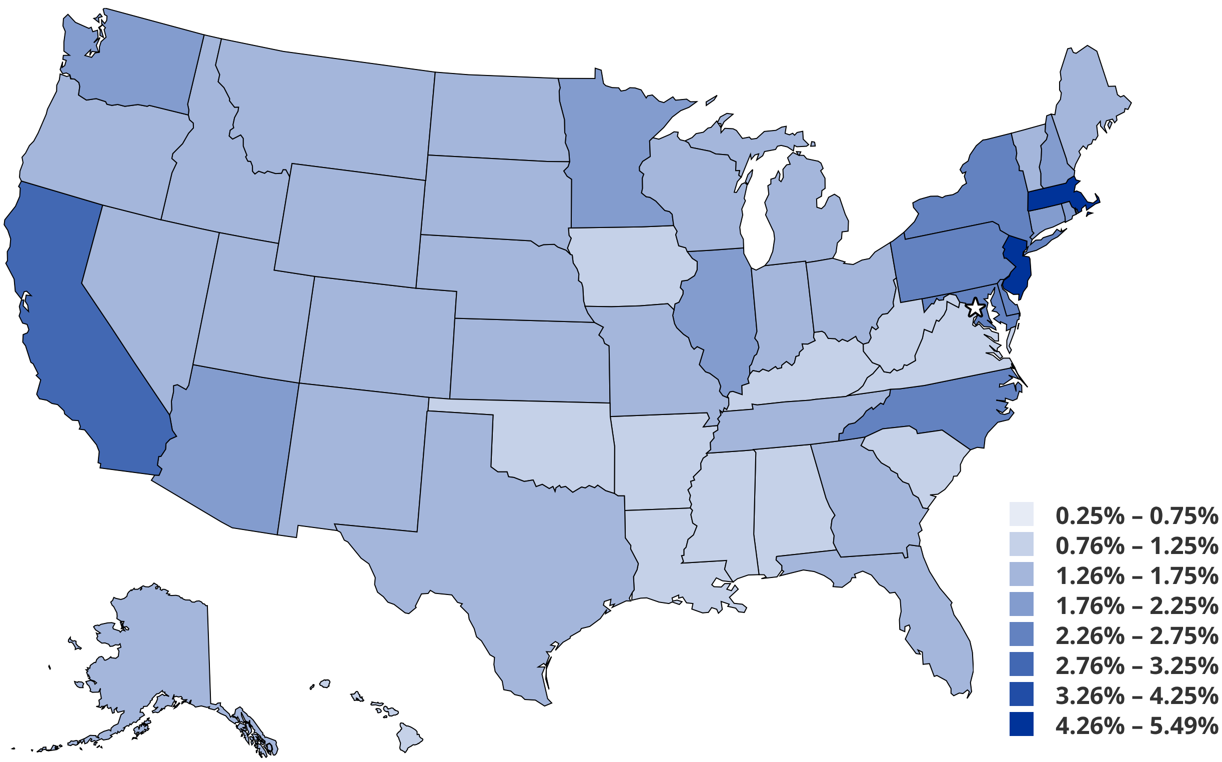
Source(s):
Emsi Burning Glass, Job Posting Analytics, accessed 15 October 2021.

Science and Engineering Indicators

Analysis of the geographic distribution of demand for biotechnology-related talent yields a similar result as the demand for AI-related talent, although demand is concentrated within a fewer number of states. Between October 2016 and September 2021, Massachusetts (5.5%) and New Jersey (4.5%) saw the greatest demand for biotechnology-related talent (**Figure KTI-32**; Table SKTI-26). Only 11 other states saw demand for biotechnology-related talent above the overall demand for this talent in the United States (1.9%). Most of these states are found along the East Coast (i.e., District of Columbia, Delaware, Maryland, and North Carolina) as well as California, Minnesota, and Illinois.

Figure KTI-32

Unique biotechnology-related job postings as a share of all unique job postings, by state: October 2016–September 2021



Note(s):
See Table SKTI-26 for a detailed breakdown of total unique job postings and total unique biotechnology-related job postings by U.S. state. Job postings per 100,000 people are based on the U.S. Census 2019 population totals by state.

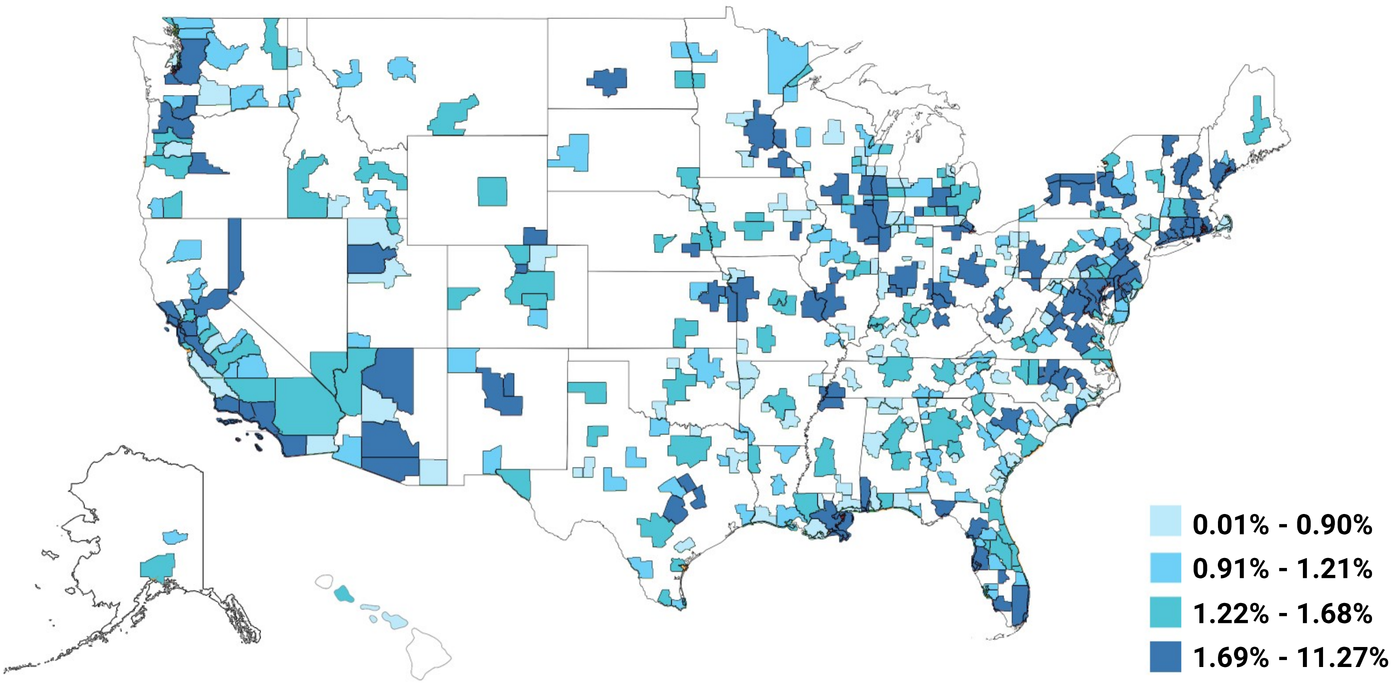
Source(s):
Emsi Burning Glass, Job Posting Analytics, accessed 15 October 2021.

Science and Engineering Indicators

Biotechnology-related job postings are concentrated in a smaller number of metropolitan areas (**Figure KTI-33**). Twelve MSAs had rates of biotechnology-related job postings that were double the rate for the U.S. overall (1.9%). This group includes the MSAs of Trenton-Princeton, NJ (11.3% of all job postings); Durham-Chapel Hill, NC (8.4%); Boston-Cambridge-Newton, MA-NH (6.4%); Oxnard-Thousand Oaks-Ventura, CA (5.8%); San Diego-Chula Vista-Carlsbad, CA (5.0%); San Francisco-Oakland-Berkeley, CA (4.8%); Raleigh-Cary, NC (4.6%); Greenville, NC (4.6%); and Kalamazoo-Portage, MI (4.6%).

Figure KTI-33

Unique biotechnology-related job postings as a share of all unique job postings, by metropolitan statistical area: October 2016–September 2021



MSA = metropolitan statistical area.

Note(s):
The data represented in the table indicate the top 20 MSAs with job postings related to biotechnology. The map represents all biotechnology job postings within the 384 MSAs in the United States. Job postings per 100,000 people are based on the 2019 MSA Census Population numbers.

Source(s):
Emsi Burning Glass, Job Posting Analytics, accessed 15 October 2021.

Science and Engineering Indicators

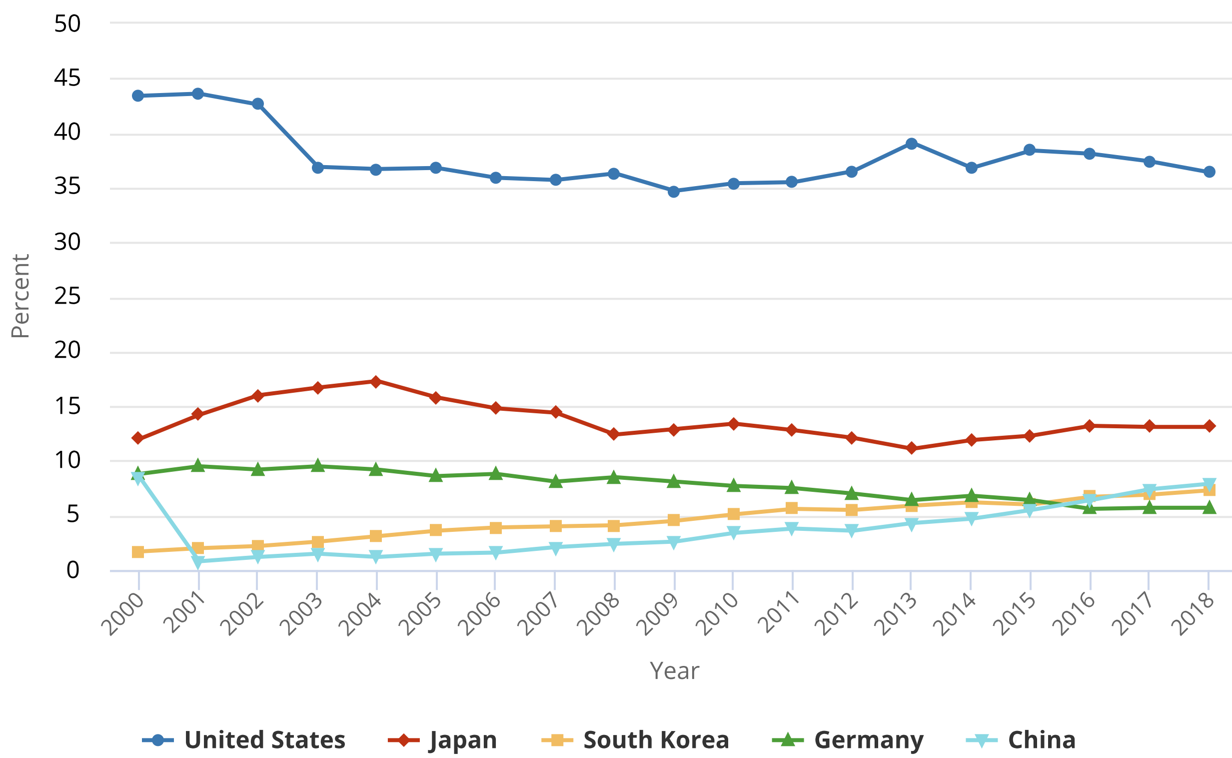
The MSAs with the highest concentration of biotechnology-related postings (i.e., percentage share of total U.S. postings) differed from the MSAs with the highest intensity (i.e., postings per 100,000).[24] Oxnard-Thousand Oaks-Ventura, CA (5.8%), and San Diego-Chula Vista-Carlsbad, CA (5.0%), had high concentrations of biotechnology-related postings across the MSAs but also had comparatively larger populations. Compared to some other smaller MSAs, the intensity of biotechnology-related postings was smaller, with 2,166 per 100,000 persons living in Oxnard-Thousand Oaks-Ventura, CA, and 2,152 postings per 100,000 living in San Diego-Chula Vista-Carlsbad, CA. Conversely, Madison, WI (3.3%), and Ann Arbor, MI (3.7%), had lower concentrations of biotechnology-related postings but higher intensities: 2,881 and 2,652 postings per 100,000 population, respectively. Some MSAs with high concentrations of biotechnology-related postings, like Trenton-Princeton, NJ, Durham-Chapel Hill, NC, and Boston-Cambridge-Newton, MA-NH, also have comparatively high intensities.

Biotechnology Patents

Patenting is closely linked to invention and indicates the transformation of knowledge into new products and services. Based on OECD's (2021a) definition of biotechnology, inventors living in the United States (36%) patent most of the biotechnology-related patent families filed within the five intellectual property offices (IP5), and this share has been fairly stable since 2010 (**Figure KTI-34**).[25] The next-largest producers are Japan (13%), China (8%), South Korea (7%), and Germany (6%). Germany's share has been on a long-term downward trend since 2001, whereas South Korea's and China's shares have been on an upward trend since 2001. The share of USPTO utility patents in biotechnology granted to inventors living in the United States (as defined by the World Intellectual Property Organization [WIPO]) is also stable, ranging between 55% and 57% during the period 2010–20.

Figure KTI-34

Country share of biotechnology-related patents, based on the new biotechnology definition, by top 5 countries: 2000–18



Note(s):
Patents are based on IP5 patent families and percentages based on fractional counts. The IP5 members are the European Patent Office, Japan Patent Office, Korean Intellectual Property Office, National Intellectual Property Administration of the People's Republic of China, and United States Patent and Trademark Office.

Source(s):
Organisation for Economic Co-operation and Development, STI Micro-data Lab, Intellectual Property Database, https://www.oecd.org/sti/intellectual-property-statistics-and-analysis.htm, accessed 8 October 2020.

Science and Engineering Indicators

Economic Impacts of Biotechnology

Although the direct benefits of biotechnology stemming from increased employment for highly skilled and well-paid workers and increased sales revenues are small compared to other industries, the indirect benefits of biotechnology, including improvements in quality of life, economic growth, better health products and services, and a cleaner environment, are substantial. An illustrative example of the direct and indirect impacts of biotechnology on the U.S. economy can be readily seen during the pandemic. Several of the COVID-19 vaccines were developed using biotechnology, resulting in increased sales and profits for companies researching and producing the vaccines (Terry 2021; Johnson 2021). More importantly, the vaccines saved thousands of lives and boosted the U.S. economy by reducing voluntary social distancing and official lockdown requirements (Gagnon, Kamin, and Kearns 2021). This section describes some of the direct and indirect impacts of biotechnology, more generally, in the U.S. economy.

Estimating the direct effects of biotechnology to the U.S. economy is difficult because biotechnology is used in many industries, and there is no consensus on what industries are biotechnology. Many private companies have evaluated the market value of biotechnology companies in the United States; depending on their definition of biotechnology, these estimates range between $135 billion in 2020 to $561 billion in 2017 (IBISWorld 2021b; PhRMA 2019). In terms of value-added output, biotechnology companies produced $294 billion in 2017 (PhRMA 2019), or roughly 1.5% of GDP. Although employment in these companies is relatively small (less than 1% of the U.S. workforce, based on PhRMA and IBISWorld 2021a), average compensation for biotechnology workers ($127,000) is more than double that of the average U.S. worker ($61,000). This roughly amounts to $103 billion in labor income and $20 billion in federal personal tax revenue (PhRMA 2019).

Like the COVID-19 vaccine, the products produced from biotechnology inventions and innovations can have substantial effects on mortality and morbidity, and large economic benefits from both. For example, biotechnology in agriculture has resulted in genetically engineered crops that have and can be used in the future to reduce global food insecurity. In their literature review, Berman et al. (2013) found that several studies demonstrated the benefits of first-generation crops to farmers in many developing countries and the consequential positive effects on national GDP and gross national product values, thus increasing the ability of governments to invest in infrastructure and improve the health and well-being of their populations. In medical application of biotechnology, from 1980 to 2014, more than 260 novel human therapeutics covering 230 indications have been marketed in the United States (Evens and Kaitin 2015). With the rising number of Americans with chronic conditions, many of these biotechnology-based medicines are used to treat symptoms associated with them and to allow those individuals to work productively and have a long life (Boersma, Black, and Ward 2020; Evens and Kaitin 2015). Industrial biotechnology also has great potential for mitigating climate change by using enzymes and microorganisms to make bio-based products in a diverse variety of industry sectors (e.g., agricultural biomass) (OECD 2011). These scientific breakthroughs from biotechnology have laid the foundation for fundamentally new capabilities that have the potential to transform society, the environment, and the economy.

Conclusion

KTI industries are central to the U.S. R&D enterprise in multiple ways. Compared to their share of output and employment, KTI industries perform and fund a disproportionately large share—more than half—of U.S. business R&D. They produce innovative products and technologies that benefit other industries and the economy and society more broadly.

In the United States, IT and other information services, software publishing, and computer, electronic, and optical products industries account for more than half of the value added generated by KTI industries. The most notable change in U.S. KTI production in the last two decades is the faster growth in KTI services value added compared to manufacturing. KTI industries employ disproportionately more workers in STEM occupations compared to other industries and have high concentrations of foreign-born workers. Foreign-born STEM workers in KTI industries are primarily from India, China, the Philippines, Vietnam, and Mexico.

KTI industries continue to support various aspects of the response to the COVID-19 pandemic, including the supply of medical products, the transition to remote work and online learning, and the digital delivery of health care services. As a result, the value added generated by KTI industries increased in 2020 even as GDP declined, led by increases in medical instruments, pharmaceuticals, IT and other information services, software publishing, and computer, electronic, and optical products.

U.S. KTI production is concentrated and specialized domestically. Fifteen states account for three-fourths of the total value added generated by KTI industries. Globally, the United States leads production activities of KTI services industries (IT and other services, software publishing, and scientific research and development), whereas China leads KTI manufacturing industries (except for air and spacecraft, medical and dental instruments, and pharmaceuticals). Slower growth of KTI manufacturing value added in the United States and other major economies compared to China has resulted in a decline in their global shares of KTI production in the last two decades.

As other countries' KTI output has increased, so too has their share of exports. As a result, the U.S. global export share has fallen over the last decade, and the U.S. KTI trade deficit has widened. Although its share has fallen, the United States is the world's third-largest exporter of KTI products, behind China and Germany. U.S. KTI exports overall, however, contain a smaller share of foreign value, indicating less reliance on foreign inputs when compared to China and Germany.

Investment in enabling technologies, like biotechnology and AI, has been a high priority for U.S. federal R&D funding over the last few years. Many KTI industries are either developing or utilizing biotechnology and AI technologies, including pharmaceuticals, software publishing, and IT services. The pharmaceuticals industry performs the most biotechnology R&D in the United States.

The demand for AI- and biotechnology-related skills has increased over the last few years in the United States, although it is concentrated in a few states in the West and the Northeast. Venture capital financing for both AI and biotechnology sectors is also highly concentrated in the West and the Northeast, which is consistent with these regions producing the most KTI output.

Although biotechnology and AI are primarily performed in a few industries, the diffusion and use of these technologies are likely to give rise to new, technologically advanced industries, products, and services. The data presented in this report indicate that the United States and China lead in research and commercialization of AI technologies, and while the United States continues to lead in business R&D performance and patenting in biotechnology, other countries, including China, are rapidly building their biotechnology capacity.

Glossary

Definitions

Air and spacecraft and related machinery, manufacture of: This industry includes the manufacture of airplanes for the transport of goods or passengers, for use by defense forces, for sport, or for other purposes; helicopters; gliders and hang gliders; dirigibles and hot air balloons; parts and accessories of the aircraft of this class; ground-flying trainers; spacecraft and launch vehicles, satellites, planetary probes, orbital stations, shuttles; intercontinental ballistic missiles; overhaul and conversion of aircraft or aircraft engines; and aircraft seats.

Chemicals and chemical products, manufacture of: This industry includes the transformation of organic and inorganic raw materials by a chemical process and the formation of products.

Computer, electronic, and optical products, manufacture of: This industry includes the manufacture of computers, computer peripherals, communications equipment, and similar electronic products, as well as the manufacture of components for such products. Also included is the manufacture of consumer electronics; measuring, testing, navigating, and control equipment; irradiation, electromedical, and electrotherapeutic equipment; optical instruments and equipment; and magnetic and optical media.

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.

Electrical equipment, manufacture of: This industry includes the manufacture of products that generate, distribute, and use electrical power. Also included is the manufacture of electrical lighting, signaling equipment, and electric household appliances.

European Union (EU): The EU comprises 27 member nations: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, and Sweden. The United Kingdom withdrew from the EU on 1 February 2020. Unless otherwise noted, data on the EU include all 27 member countries.

Global value chain (GVC): 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.

Gross domestic product (GDP): The market value of all final goods and services produced within a country for a given period of time.

Information technology (IT) and information services: This industry is the composite of International Standard Industrial Classification of All Economic Activities (ISIC) sectors 62 (computer programming, consultancy, and related activities) and 63 (information service activities). ISIC 62 includes the following activities of providing expertise in the field of information technologies: writing, modifying, testing, and supporting software; planning and designing computer systems that integrate computer hardware, software, and communication technologies; on-site management and operation of clients' computer systems and/or data processing facilities; and other professional and technical computer-related activities. ISIC 63 includes the activities of Web search portals, data processing and hosting activities, and other activities that primarily supply information.

Knowledge- and technology-intensive (KTI) industries: Industries classified by the Organisation for Economic Co-operation and Development (OECD) as high R&D intensive and medium-high R&D intensive industries. The OECD defines R&D intensity as the ratio of an industry's business R&D expenditures to its value added.

Machinery and equipment not elsewhere classified (nec), manufacture of: This industry includes the manufacture of machinery and equipment that act independently on materials either mechanically or thermally or perform operations on materials (such as handling, spraying, weighing, or packing), including their mechanical components that produce and apply force, and any specially manufactured primary parts. This includes the manufacture of fixed and mobile or handheld devices, regardless of whether they are designed for industrial, building, and civil engineering, agricultural, or home use. Also included is the manufacture of special equipment for passenger or freight transport within demarcated premises.

Medical and dental instruments and supplies, manufacture of: This industry includes the manufacture of laboratory apparatus, surgical and medical instruments, surgical appliances and supplies, dental equipment and supplies, orthodontic goods, and dentures and orthodontic appliances. Also included is the manufacture of medical, dental, and similar furniture, where the additional specific functions determine the purpose of the product, such as dentist chairs with built-in hydraulic functions.

Motor vehicles, trailers, and semi-trailers, manufacture of: This industry includes the manufacture of motor vehicles for transporting passengers or freight. Also included is the manufacture of various parts and accessories, as well as the manufacture of trailers and semi-trailers.

Pharmaceuticals (manufacture of basic pharmaceutical products and pharmaceutical preparations): This industry includes the manufacture of basic pharmaceutical products and pharmaceutical preparations. Also included is the manufacture of medicinal chemical and botanical products.

Railroad, military vehicles, and transport not elsewhere classified (nec), manufacture of: This industry is the composite of International Standard Industrial Classification of All Economic Activities (ISIC) 302 (manufacture of railway locomotives and rolling stock), ISIC 304 (manufacture of military fighting vehicles), and ISIC 309 (transport equipment nec). ISIC 302 includes the manufacture of electric, diesel, steam, and other rail locomotives; self-propelled railway or tramway coaches, vans, and trucks and maintenance and service vehicles; railway and tramway rolling stock, not self-propelled; specialized parts of railway and tramway locomotives and of rolling stock; mechanical and electromechanical signaling, safety, and traffic control equipment for railways, tramways, inland waterways, roads, parking facilities, airfields, etc.; mining locomotives and mining rail cars; and railway car seats. ISIC 304 includes the manufacture of tanks, armored amphibious military vehicles, and other military fighting vehicles. ISIC 309 includes the manufacture of transport equipment other than motor vehicles and rail, water, air, and space transport equipment and military vehicles. It includes manufacture of motorcycles, bicycles and invalid carriages, hand-propelled vehicles, and vehicles drawn by animals.

Scientific research and development (R&D): This industry includes the activities of three types of R&D: (1) basic research: experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, without particular application or use in view; (2) applied research: original investigation undertaken in order to acquire new knowledge, directed primarily toward a specific practical aim or objective; and (3) experimental development: systematic work, drawing on existing knowledge gained from research and/or practical experience, directed to producing new materials, products, and devices; installing new processes, systems, and services; and improving substantially those already produced or installed.

Software publishing: This industry includes publishing of ready-made (non-customized) software: operating systems, business and other applications, and computer games for all platforms.

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

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

ABS: Annual Business Survey

ACS: American Community Survey

AI: artificial intelligence

BEA: Bureau of Economic Analysis

BLS: Bureau of Labor Statistics

BRDIS: Business R&D and Innovation Survey

BRDS: Business Research and Development Survey

COVID-19: coronavirus disease 2019

DOE: Department of Energy

EU: European Union

GDP: gross domestic product

GPT: general purpose technology

GVC: global value chain

ICT: information and communications technologies

IP5: forum of the five largest intellectual property offices in the world

IT: information technology

KTI: knowledge- and technology-intensive

M&A: mergers and acquisitions

MSA: metropolitan statistical area

NCSES: National Center for Science and Engineering Statistics

nec: not elsewhere classified

NITRD: Networking and Information Technology Research and Development

OECD: Organisation for Economic Co-operation and Development

OIS: Office of Immigration Statistics

R&D: research and development

TiVA: Trade in Value Added

S&E: science and engineering

STEM: science, technology, engineering, and mathematics

STW: skilled technical workforce

USDA: Department of Agriculture

USPTO: United States Patent and Trademark Office

WIPO: World Intellectual Property Organization

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Notes

1 For more information on the OECD's methodology in identifying R&D intensive industries, see **Technical Appendix** and Galindo-Rueda and Verger (2016). In addition to R&D intensity, KTI industries may be defined using other measures, including high concentrations of workers in STEM occupations (e.g., Wolf and Terrell 2016) or high rates of patenting and innovation activities. However, we are not aware of internationally comparable data for defining KTI industries using these other measures.

2 Specifically, KTI industries are defined as those belonging to the high and medium-high R&D intensity groups (see **Technical Appendix** and Galindo-Rueda and Verger 2016). A detailed description of each of these industries is provided in the Glossary. The OECD taxonomy also includes the weapons and ammunition industry. This report, however, does not present data on weapons and ammunition, a relatively small industry whose value added accounts for less than 1% of global KTI value added. (See historical data for this industry in the ***Indicators 2020*** edition of this report.)

3 The U.S. production and employment data have been crosswalked from the 2012 North American Industry Classification System (NAICS) to the 4th revision of the International Standard Industrial Classification of All Economic Activities (ISIC, Rev.4) for comparability with the international data. See the **Technical Appendix** for more details.

4 While some COVID-19 impacts can be explicitly identified in some components of GDP—for instance, the impacts of recovery programs like unemployment insurance or the Paycheck Protection Program on aggregate federal government spending—the total effects of the COVID-19 pandemic cannot be separately identified in the value-added data because the impacts are embedded in source data. For more information, see BEA (2021b).

5 As of the time this report was compiled, the U.S. Food and Drug Administration continues to track shortages in medical devices and supplies throughout the COVID-19 pandemic, primarily in personal protective equipment, testing supplies equipment, and ventilation-related products: **https://www.fda.gov/medical-devices/coronavirus-covid-19-and-medical-devices/medical-device-shortages-during-covid-19-public-health-emergency**.

6 See Dunn (2021) for a chronicle of supply chain impacts since the beginning of the pandemic.

7 See **Technical Appendix** for details about the methodological approach to estimating employment in KTI industries.

8 For more information on the definition of the STEM workforce categories, including the STW, see *Indicators 2022* report, "[2022] The STEM Labor Force of Today: Scientists, Engineers, and Skilled Technical Workers."

9 NCSES defines underrepresented minorities as Blacks or African Americans, Hispanics or Latinos, and American Indians or Alaska Natives whose representation in S&E education and S&E employment is smaller than their representation in the U.S. population (NCSES ***WMPD*** 2021).

10 Some studies have found citizenship to be underreported in U.S. federal surveys like the ACS and the Current Population Survey. In particular, the number of naturalized citizens is found to be overestimated in Census and BLS data, possibly because some noncitizens misreport as citizens. Van Hook and Bachmeier (2013) compared the 2010 ACS PUMS to naturalization records from the Office of Immigration Statistics (OIS). Based on their analysis, the ACS estimates of naturalized citizens were much higher than OIS-based estimates among immigrants from all regions of the world who have lived in the United States fewer than 5 years. Among immigrants residing in the United States for 5 years or more, the OIS-ACS discrepancy is concentrated among those born in Mexico, especially men of all ages and women aged 40 or older. In the 2019 ACS PUMS, the average number of years since naturalization for foreign-born noncitizens ranges from 14 years for workers in IT services to 19 years for those in air and space. Across all KTI industries, 19% of foreign-born workers reported being naturalized with the last 5 years, and 10% reported that their country of birth was Mexico. Hence, some of the KTI citizenship estimates should be considered lower-bound estimates.

11 The COVID-19 pandemic is the latest but not the only unpredictable event to expose the GVC's vulnerability to disruptions due to unpredictable shocks. It is only the latest in a series of disruptions that includes the 2011 earthquake and tsunami in Japan, the flooding in Thailand the same year, and Hurricane Harvey in Texas in 2017, all of which halted production and created shortages in many sectors (see Lund et al. 2020).

12 The most recent update of the TiVA database includes indicators covering 66 economies including the OECD countries, the European Union (EU) and the Group of Twenty countries (Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Mexico, Russia, Saudi Arabia, South Africa, South Korea, Turkey, United Kingdom, United States, and the EU), and several East and Southeast Asian economies and South American countries for the years 1995–2018. Indicators are available for 45 industries and provide information on the participation and contribution of industries and countries to various stages in production chains. Additional information and access to the OECD TiVA database is available at **https://www.oecd.org/industry/ind/measuring-trade-in-value-added.htm**.

13 The investment data include both disclosed and undisclosed transactions. Since a considerable number of transactions are not disclosed, disclosed transactions underestimate the magnitude of total investment. Hence, Arnold, Rahkovsky, and Wang's (2020) estimates of total investment are, at best, a lower-bound estimate of the actual level of investment.

14 The top 25 AI-related skills identified by Emsi Burning Glass are algorithms, Apache Spark, artificial neural networks, big data, blockchain, computer vision, data science, deep learning, distribute computing, Internet of Things, machine learning, machine learning algorithms, mathematical modeling, natural language processing, Pandas (Python package), predictive analytics, predictive modeling, R (programming language), robotic process automation, Scala (programming language), speech recognition, statistical modeling, TensorFlow, time series, and unstructured data. More information on the Emsi Burning Glass data is provided in the **Technical Appendix**.

15 The acceleration in growth rate during the pandemic is likely due to several different reasons in addition to the pre-pandemic growth that was already occurring in demand for AI-related skills. According to a 2017 study by the McKinsey Global Institute (Manyika et al. 2017), automation and AI will require an estimated 14% of the global workforce to switch occupations or acquire new skills by 2030. It is possible that the increase in AI-related job postings is driven by the need for a more AI-capable workforce, and employers are seeking to close the projected skills gap by 2030. This is supported by an April 2021 survey by the McKinsey Global Institute (Billing et al. 2021), which found that 58% of executives believe that closing the skills gap in their workforce is a higher priority now than it was pre-pandemic.

16 In recent years, greater attention has been paid to the rise of "superstar" metropolitan areas that have seen their economies grow at rates exceeding economic growth in the United States overall. According to a 2019 study by the Brookings Institution and the Information Technology and Innovation Foundation (Atkinson, Muro, and Whiton 2019), five metropolitan areas in the United States—San Francisco (California), Seattle (Washington), San Jose (California), Boston (Massachusetts), and San Diego (California)—accounted for over 90% of growth in the United States' "innovation sector" between 2005 and 2017. The study also found that these superstar metropolitan areas have seen a greater increase in employment and jobs that pay higher wages.

17 A recent paper on the development and use of the technology module by the ABS and preliminary findings from the data contain new insights about the level and distribution of GPTs, especially AI, adopted by business (Zolas et al. 2020). The sample size makes the survey one of the largest and most up-to-date data sets available on advanced technology adoption. In particular, small and younger firms are adequately represented. The survey asked three detailed questions: about digitization, cloud computing, and advanced business technologies, including AI-related technologies such as guided vehicles, machine learning, machine vision, natural language processing, and voice recognition software.

18 OECD (2013) also provides a list-based definition (although not exhaustive) to serve as an interpretative guideline to the single definition. It includes DNA or RNA, proteins and other molecules, cell and tissue culture and engineering, process biotechnology techniques, gene and RNA vectors, bioinformatics, and nanobiotechnology. Data on business biotechnology R&D performance for the United States and other countries follow the OECD broad and list-based definition of biotechnology. Other data sources discussed in this section use different definitions. For more information on the different definitions of biotechnology used in each data set, see **Technical Appendix**.

19 More information on the venture capital data from PitchBook is provided in the **Technical Appendix**.

20 The 2010–16 data are from the Business R&D and Innovation Survey (BRDIS), and the 2017–18 data are from BRDS. The survey questions regarding R&D performance on biotechnology between the two surveys differ in how they define biotechnology. In BRDIS, biotechnology is "the use of cellular and bio-molecular processes to solve problems or make useful products." In BRDS, biotechnology is defined according to the OECD definition, that is, "the application of science and technology to living organisms, as well as parts, products and models thereof, to alter living or non-living materials for the production of knowledge, goods and services." Additionally, the respondent can access a list-based definition (also following the OECD) that states: "The following list provides examples of biotechnology techniques and applications. The list is not intended to be exhaustive, but it is indicative of the types of activities included in the definition of biotechnology, including: DNA/RNA; proteins and other molecules; cell and tissue culture and engineering; process biotechnology techniques; gene and RNA vectors; bioinformatics; and nanobiotechnology."

21 Powell, Koput, Bowie, and Smith-Doerr (2002) found that venture capital firms were more likely to fund smaller and more science-focused biotechnology companies and that more stable and older biotechnology startups were more likely to secure funding from a nonlocal source. In addition, they found that venture capital investments in Boston and the Bay Area tend to stay local to their respective regions.

22 NIH funding on biotechnology is only a subset of federal funds on biotechnology R&D. Other federal agencies—including the National Institutes of Food and Agriculture, Department of Defense, and Department of Energy—also fund biotechnology R&D, but these other agencies do not produce a comprehensive measure of funding on biotechnology. Arguably, most biotechnology R&D is on medical applications, and examination of NIH funding on biotechnology provides a meaningful indicator of federal support for biotechnology overall.

23 The top 25 biotechnology-related skills identified by Emsi Burning Glass are biopharmaceuticals, biostatistics, case report forms, clinical pharmacy, clinical research, clinical study design, clinical trial management systems, clinical trials, drug development, drug discovery, electronic data capture, good clinical practices, International Council for Harmonisation of Technical Requirement for Pharmaceuticals for Human Use guidelines, key opinion leader development, life sciences, medical affairs, medical devices, medical guideline, non-disclosure agreement (intellectual property law), pharmaceuticals, pharmacovigilance, pre-clinical development, regulatory filings, scientific literature, and Title 21 of the Code of Federal Regulations. More information on the Emsi Burning Glass data is provided in the **Technical Appendix**.

24 See section "**Demand for Workers with AI-Related Skills in the United States**" for a discussion of intensity versus concentration.

25 The OECD (2021a) also curates an indicator for biotechnology IP5 patent families based on the World Intellectual Property Organization (see **Technical Appendix** for differences in biotechnology definitions). Although the absolute number of patent families attributable to the United States varies by definition, the magnitude and trend in U.S. share of total biotechnology IP5 patent families are similar across definitions.

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