Industry Activities

Production and Trade of Knowledge- and Technology-Intensive Industries

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Executive Summary

Key takeaways:

- Knowledge- and technology-intensive (KTI) industries contribute globally more than $9 trillion in output, accounting for 11% of global gross domestic product (GDP). KTI industries are defined by their research and development (R&D) intensity—the ratio of an industry's R&D expenditures to its value-added output—and consist of five high R&D intensive industries and eight medium-high R&D intensive industries.
- The United States is the world's largest producer of output in high R&D intensive industries, accounting for nearly a third of global production. These industries are manufacturing of aircraft; pharmaceuticals; computer, electronic, and optical products; computer software publishing; and scientific R&D services. China and the European Union (EU) are the second-largest producers (about 20% global share each).
- China is the world's largest producer in medium-high R&D intensive industries (26% of global output), followed by the EU and the United States (22%–23%). These include information technology (IT) services, machinery, transportation equipment, and scientific instruments.
- The United States and China are investing heavily in research and commercialization of artificial intelligence (AI) technologies. Business adoption of AI technologies is occurring across the world, including North America, Europe, Asia-Pacific, Middle East, India, and other developing countries.

R&D and other activities that advance science and technology play a central role in a country's economic growth and competitiveness. This report examines trends in production and trade of KTI industries of the United States and other major world economies. Knowledge and technology intensity of an industry can be measured in different ways, including R&D performance, employment of high skilled workers, and patenting and innovation activities. This report focuses on industry R&D intensity: the ratio of an industry's business R&D expenditures to its value-added output. These industries make large investments in R&D, and produce goods and services embodied with advanced technologies. Other industries, and society as a whole, benefit from and use technologies that originate from KTI industries.

Industries with the highest ratios of R&D expenditures to output are labeled in this report as "high R&D intensive" industries. Among these industries, the United States is the world's largest producer, accounting for nearly a third of global production. Although they account for a small share of U.S. industrial output and employment, these industries fund a disproportionately large share of U.S. business R&D. China and the EU are the second-largest global producers of output, each with about a 20% global share. Global output of high R&D intensive industries has more than doubled in the past 15 years, reflecting both price and quantity growth. The U.S. global share has remained stable over the last decade while the EU share declined and China's rose rapidly.

In medium-high R&D intensive industries, the United States has a smaller global share (22%) compared to the largest producer, China (26%). China has rapidly increased its output over the last decade. U.S. output grew slower than China's, and the U.S. global share remained roughly stable. The EU's output has stagnated over the last decade, resulting in a notable decline in its global share.

The United States is the world's third largest exporter of KTI products, behind the EU and China. The U.S. global export share has fallen over the last decade and the U.S. trade deficit has widened. Accounting for domestic intermediate production, the United States has higher exports and a far smaller trade deficit on a value-added basis in computer, electronic, and optical products, which are part of high R&D intensive products.

This report also examines AI technologies, which are predicted to have widespread economic and societal impact in the coming decade. Many KTI industries are either developing or utilizing AI technologies, including software publishing, IT services, and computer, electronic and optical products industries. Furthermore, AI is likely to give rise to new technologically advanced industries, products, and services. The United States and China are investing heavily in the research and commercialization of AI. Both countries have AI initiatives that include the following stated goals: increase public funding of AI R&D, develop and improve the skills necessary at the workplace to effectively utilize AI, and promote collaboration between the private sector, universities, and government. Company adoption of AI technologies, measured by AI being embedded in at least one business unit of the company, is occurring across the world, including North America, Europe, Asia-Pacific, Middle East, and India and other developing countries.

Introduction

This report covers three main areas. The first is an analysis of global production trends of KTI industries; the second is an analysis of global trade in KTI products; and the third is a discussion of AI technologies and their impact in the global economy. Many KTI industries are either developing or utilizing AI technologies, including software publishing, IT services, and computer, electronic and optical products industries. Furthermore, AI is likely to give rise to new technologically advanced industries, products, and services.

KTI industries consist of industries that have a relatively high ratio of business R&D expenditures to their value-added output. These industries make large investments in R&D and produce technologically advanced goods and services. The importance of science and technology in commercial activity extends beyond R&D intensive industries. This report also highlights the role and significance of knowledge and technology in the agriculture industry, which is not included in the KTI classification utilized in this report. Agriculture is an intensive user of advanced and science-based technologies including pharmaceuticals, biotechnology, and remote sensors.

This report uses a variety of data sources. A description of the data sources is provided in the **Technical Appendix**. This report's discussion of regional and country patterns and trends in the production and trade of output of KTI industries focuses on the United States; three economies and regions—China, the EU, and Japan; and a group of Asian economies, including India, South Korea, Taiwan, and the Philippines. This group of Asian economies collectively account for a significant share of global KTI production.

Knowledge and technology intensity of an industry can be measured in different ways, including R&D performance, employment of high skilled workers, and patenting and innovation activities. R&D intensity, the focus of this report, is an important measure of R&D performance, but an incomplete measure of knowledge and technology intensity. Other facets of knowledge and technology are analyzed in the following *Science and Engineering Indicators 2020* reports: "Science and Engineering Labor Force" analyzes industry employment of science and engineering workforce, "Research and Development: U.S. Trends and International Comparisons" analyzes industry R&D performance, and "Invention, Knowledge Transfer, and Innovation" analyzes patenting and innovation activities by industry. Through its industry output lens, this report complements the other reports to provide a comprehensive picture of the state of knowledge and technology creation, transfer, and adoption, and the role they play in a country's economic competitiveness (in terms of production and trade) in the global arena. The R&D-intensity-based industry classification permits international comparison of KTI industries. We are not aware of internationally comparable data for defining KTI industries using other measures, such as employment-based classifications that are utilized by the U.S. Bureau of Labor Statistics (Wolf and Terrell 2016).

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

This section examines the importance of knowledge- and technology-intensive (KTI) industries in the global economy, and the positions of the United States and other major economies in global KTI industry production. In this report, KTI industries consist of high and medium-high R&D intensity industries as identified internationally in a report by the Organisation for Economic Co-operation and Development (OECD).[1] Industries are classified into R&D intensity groups using the ratio of an industry's business R&D expenditures to its value-added output.

Value added is a net measure of output; it is the difference between the total revenue generated from the sale of an industry's output and the total cost of inputs that were used in production such as the cost of labor, raw materials, and services purchased from other businesses. For production activities that take place within a country's geographic borders, value added from all industries at all stages of production equals GDP, thus value added is a measure of an industry's contribution to overall GDP. Value added is used in the computation of R&D intensity instead of gross output because as a net measure, it avoids double counting of intermediate production.

Five industries are classified as high R&D intensive—aircraft; computer, electronic, and optical products; pharmaceuticals; scientific R&D services; and software publishing (**Table 6-1**). Eight industries are classified as medium-high R&D intensive—chemicals excluding pharmaceuticals; electrical equipment; IT services; machinery and equipment; medical instruments; motor vehicles; railroad and other transportation; and weapons (see sidebar **New Definition of KTI Industries**). These industries have lower, but still substantial levels of R&D intensity.

TABLE 6-1

Global KTI industries, by output and share of global GDP: 2018

(Billions of dollars and percent)

Industry	Value added ($billions)	Share of global GDP (%)
All KTI industries	9,020.7	11.1
High R&D intensive industries	3,241.8	4.0
Aircraft	243.1	0.3
Computer, electronic, and optical products	1,185.9	1.5
Pharmaceuticals	698.7	0.9
Scientific R&D services	652.5	0.8
Publishing (including software)	461.6	0.6
Medium-high R&D intensive industries	5,778.9	7.1
Chemicals excluding pharmaceuticals	1,026.5	1.3
Electrical equipment	655.7	0.8
IT services	1,621.8	2.0
Other machinery and equipment	1,195.2	1.5
Motor vehicles	1,109.7	1.4
Railroads and military vehicles	119.9	0.1
Weapons	50.1	0.1

GDP = gross domestic product; IT = information technology; KTI = knowledge and technology intensive.

Note(s):

Output of KTI industries is on a value-added basis. Value added is the amount contributed by a country, firm, or other entity to the value of a good or service and excludes purchases of domestic and imported materials and inputs. KTI industries include 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 for the software publishing are not available; data on the larger publishing industry, which includes software publishing, is used as a proxy for this industry. Data are not available for medical and dental instruments. World total does not include all countries and economies due to limitations in data availability. See Table S6-2 through Table S6-16.

Source(s):
IHS Markit, special tabulations (2019) of Comparative Industry Service.

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This report presents data on most of these industries. Data on software publishing are not available; instead data are presented on the publishing industry, which includes software publishing. The data presented on the publishing industry is an imperfect measure of the software publishing industry because the share of software publishing in the publishing industry varies across countries. Data on medical instruments and military vehicles are also not available. Military vehicles are part of the railroad and other transportation industry.

SIDEBAR

New Definition of KTI Industries

The previous edition of this report (*Indicators 2018:* **Industry, Technology, and the Global Marketplace**) defined knowledge- and technology-intensive (KTI) industries based on industries with strong links to science and technology as formerly designated by the Organisation for Economic Co-operation and Development (OECD). These included five knowledge-intensive services industries grouped into commercial knowledge-intensive services (financial services, business services, and information services) and public knowledge-intensive service (education and health care), five high-technology manufacturing industries (aircraft and spacecraft; pharmaceuticals; computers and office machinery; semiconductors and communications equipment; and measuring, medical, navigation, optical, and testing instruments), and five medium-high-technology industries (motor vehicles and parts, chemicals excluding pharmaceuticals, electrical machinery and appliances, machinery and equipment, and railroad and other transportation equipment). The knowledge-intensive services industries are highly aggregated and are composed of numerous detailed industries. The high and medium-high technology manufacturing industries are less aggregated than the knowledge-intensive services industries. More information on this definition and these industries can be found in the previous edition of this report.

For *Indicators 2020*, we have adopted a new, more-focused definition of KTI industries that relies on an updated OECD industry classification based on R&D intensity. This classification represents both an update and an extension to prior OECD taxonomies; it incorporates the latest revision of the International Standard Industrial Classification (ISIC Rev. 4) and extends for the first time the R&D intensity analysis to non-manufacturing industries including a broad range of services. More information on the OECD classification is available in the **Technical Appendix** that accompanies this report.

This new definition of KTI industries includes five high R&D intensive industries and eight medium-high R&D intensive industries (**Table 6-1**). The five high R&D intensive industries are aircraft; computer, electronic, and optical products; pharmaceuticals; scientific R&D services; and software publishing. The eight medium-high R&D intensive industries are chemicals excluding pharmaceuticals; electrical equipment; information technology (IT) services; machinery and equipment; medical and dental instruments; motor vehicles; railroad and other transportation; and weapons. These industries have lower, but still substantial levels of R&D intensity.

While output data are based on industry categories, trade data are based on products. The trade of KTI products and services includes products and services that closely correspond to KTI industries. The definition of KTI products and services has also been adjusted to make trade data consistent with the new definition of KTI industries.

This new classification of KTI industries overlaps almost completely with the high-technology and medium-high-technology manufacturing industries in the *2018 Indicators*. It overlaps with the commercial knowledge-intensive services in three industries—IT services, software publishing, and scientific R&D services. Finally, the new classification does not overlap with the public knowledge-intensive services. The exclusion of education, health care, financial services, and most of the industries within business services explains the large difference in reported total KTI output between *Indicators 2020* and *Indicators 2018* ($7.8 trillion compared with $23.6 trillion in 2016, the latest year of overlap between the two editions).

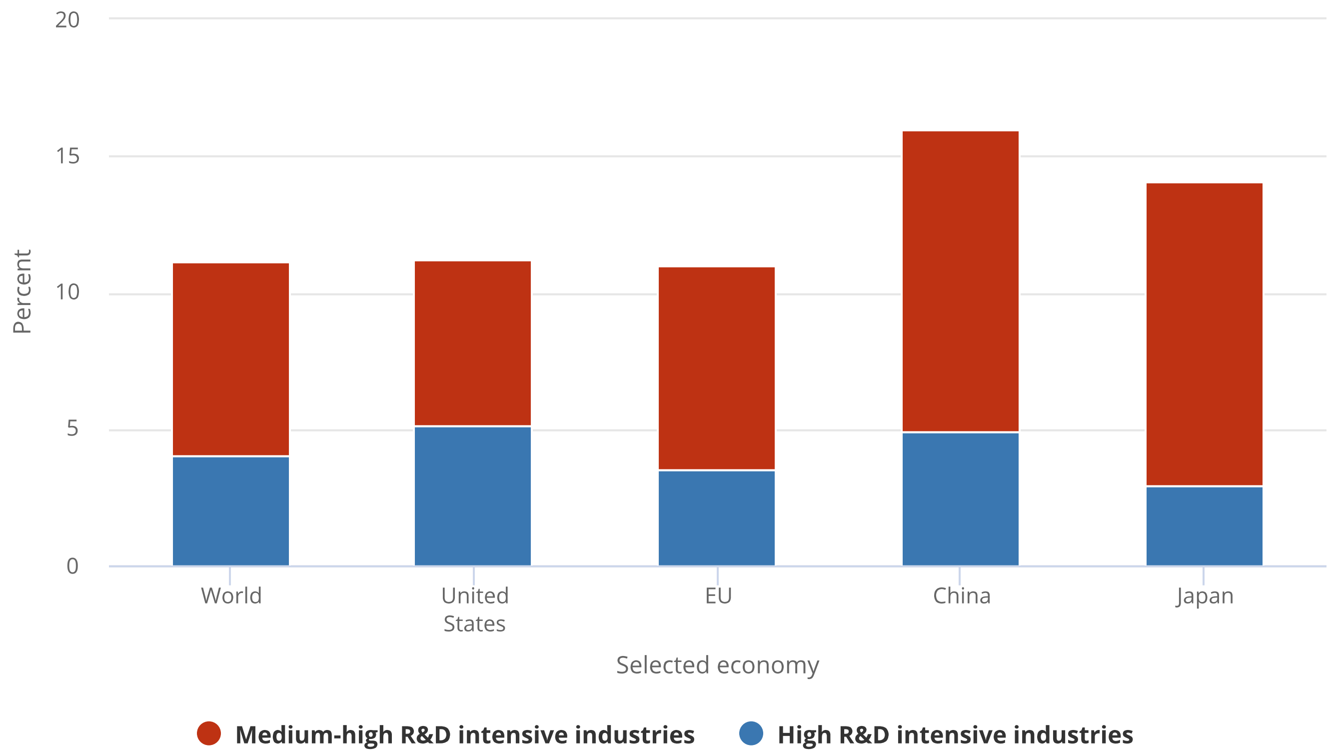
Knowledge- and Technology-Intensive Industries in the Global Economy

KTI industries contribute globally $9 trillion in value added, accounting for 11% of GDP (**Table 6-1** and Table S6-2). The medium-high R&D intensive industries produce the largest share (64%) of global KTI output, accounting for 7% of global GDP. The output of the high R&D intensive industries is comparatively lower, accounting for 4% of global GDP (**Table 6-1**).

The United States and EU both have KTI output shares of their domestic GDP at the global average (11% of GDP). China and Japan have KTI shares that are considerably larger because of much higher output shares of medium-high R&D intensive industries (**Figure 6-1**). Over the past 15 years, the KTI output shares of domestic GDP in the United States, EU, China, and Japan have remained relatively constant (**Figure 6-2**). The next two sections discuss the specific trends for high and medium-high R&D intensive industries.

FIGURE 6-1

KTI industries of selected economies, by share of domestic GDP: 2018



EU = European Union; GDP = gross domestic product; KTI = knowledge and technology intensive.

Note(s):

Output of KTI industries is on a value-added basis. Value added is the amount contributed by a country, firm, or other entity to the value of a good or service and excludes purchases of domestic and imported materials and inputs. KTI industries include high R&D intensive and medium-high R&D intensive industries classified by the Organisation for Economic Co-operation and Development. High R&D intensive industries include aircraft; pharmaceuticals; computer, electronic, and optical products; scientific research and development services; and software publishing. Data for the software publishing are not available; data on the larger publishing industry, which includes software publishing, is used as a proxy for this industry. Medium-high R&D intensive industries include weapons and ammunition; motor vehicles; medical and dental instruments; machinery and equipment; chemicals and chemical products; electrical equipment; railroad, military vehicles, and transport; and IT and other information services. Data on medical and dental instruments are not available. World total does not include all countries and economies due to limitations in data availability.

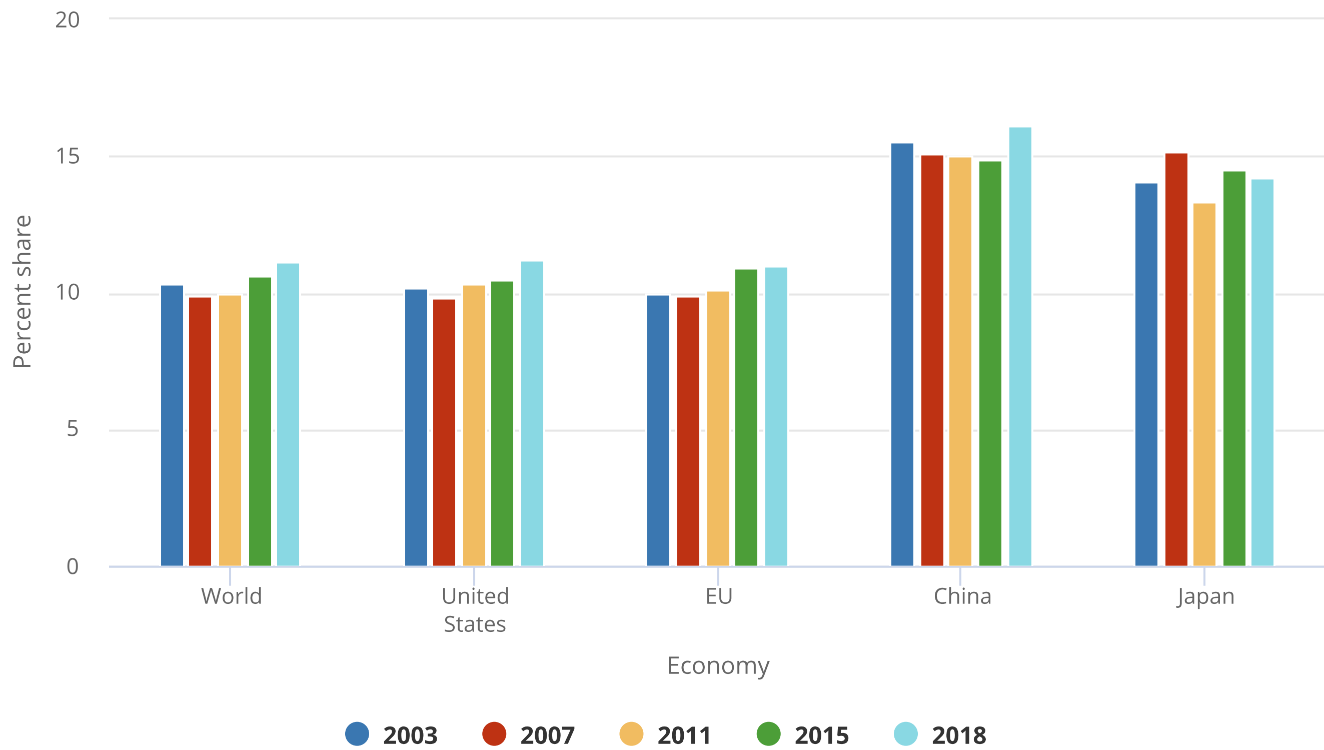
Source(s):

IHS Markit, special tabulations (2019) of Comparative Industry Service.

Science and Engineering Indicators

FIGURE 6-2

KTI industries of selected economies, by share of domestic GDP: selected years, 2003–18



EU = European Union; GDP = gross domestic product; KTI = knowledge and technology intensive.

Note(s):

Output is measured on a value-added basis. Value added is the amount contributed by a country, firm, or other entity to the value of a good or service and excludes purchases of domestic and imported materials and inputs. World total does not include all countries and economies due to limitations in data availability. See Table S6-2.

Source(s):

IHS Markit, special tabulations (2019) of Comparative Industry Service.

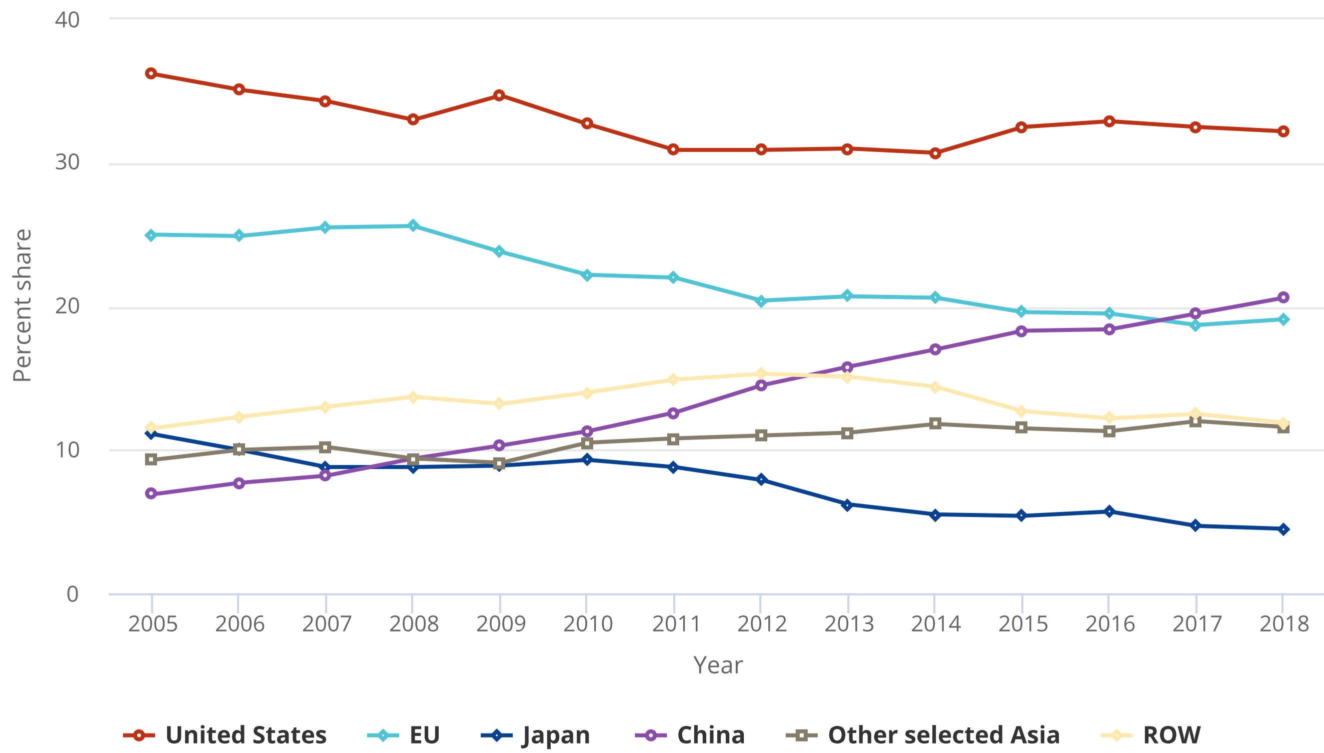
Science and Engineering Indicators

Global Trends in High R&D Intensive Industries

The United States has been the world's largest producer of output in high R&D intensive industries for three decades. It is responsible for almost a third of global output of these industries (**Figure 6-3** and Table S6-3). China and the EU are the second-largest producers with substantially lower global shares (about 20% each). Since 2002, global output of high R&D intensive industries has more than doubled, reflecting both price and quantity growth (Table S6-3). U.S. production in these industries has kept pace so the U.S. global share has remained stable. The EU's output has grown slower than global output, resulting in a decline of EU's global share. Japan's output has contracted and Japan's global share has declined sharply. China has emerged as a major producer in high R&D intensive industries over the last decade and its global share has increased rapidly.

FIGURE 6-3

Output of high R&D intensive industries for selected regions, countries, or economies: 2005–18



EU = European Union; ROW = rest of world.

Note(s):

Output is measured on a value-added basis. Value added is the amount contributed by a country, firm, or other entity to the value of a good or service and excludes purchases of domestic and imported materials and inputs. High R&D intensive industries include aircraft; pharmaceuticals; computer, electronic, and optical products; scientific research and development; and software publishing classified by the Organisation for Economic Co-operation and Development. Data for the software publishing are not available; data on the larger publishing industry, which includes software publishing, is used as a proxy for this industry. Other selected Asia includes India, Indonesia, Malaysia, the Philippines, Singapore, South Korea, Taiwan, Thailand, and Vietnam. See Table S6-3.

Source(s):

IHS Markit, special tabulations (2019) of Comparative Industry Service.

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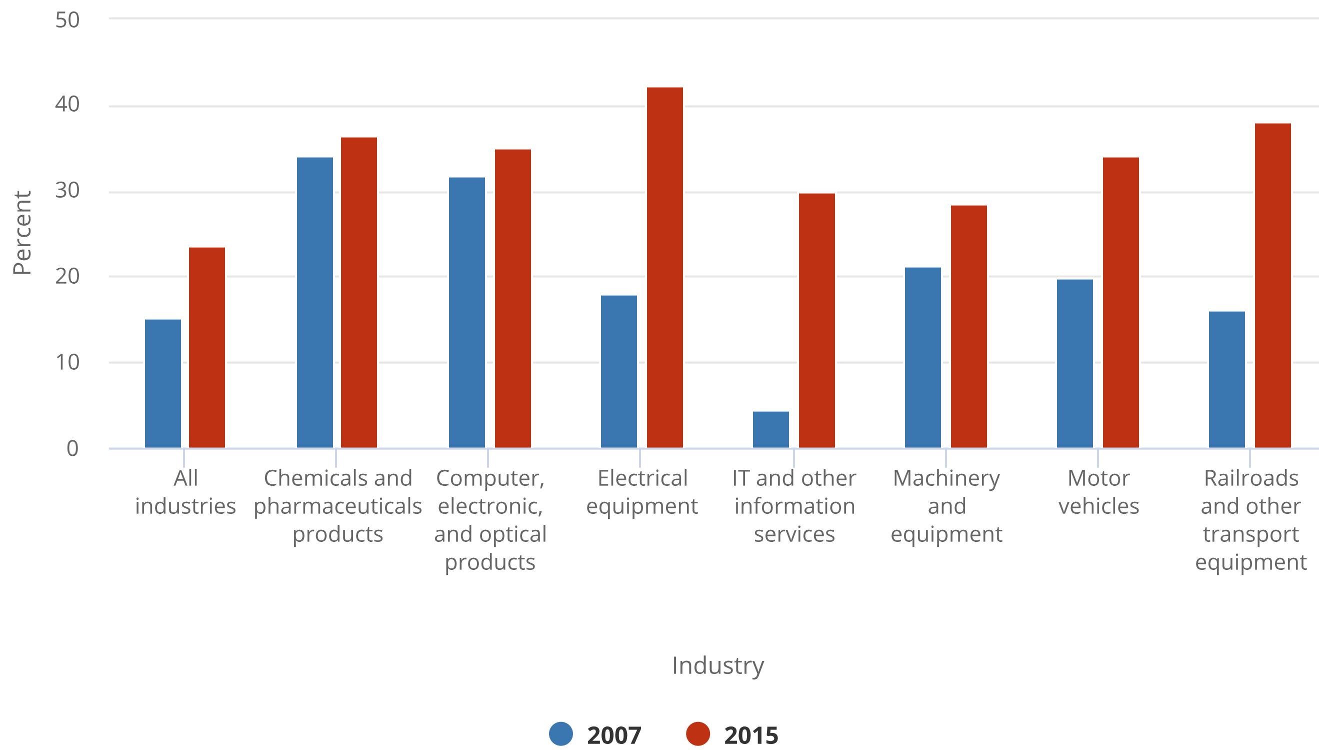
Production in most high R&D intensive industries is globalized, involving complex value chains that span multiple countries. A global value chain consists of the full range of activities that take place across the world to bring a product or service from conception to its final form. Global value chains create opportunities for countries to participate in global production by specializing in segments of production in which they have a comparative advantage rather than the production of an entire product.

The global value chains of various KTI industries differ based on whether there is a need to integrate R&D, testing, and manufacturing activities. KTI's global value chains also differ in terms of the location in the value chain where knowledge is created. In some industries innovation occurs largely in R&D activities; in other industries considerable knowledge is created in other parts of the production chain such as in manufacturing activities.

The global value chains and the globalization of production are prominent in the largest high R&D intensive industry—computer, electronic, and optical products—because components are modular and generally low weight, which keeps shipping costs low (OECD 2012:27). The foreign content share of global production of this industry, an indicator of globalization, was 35% in 2015 compared to the 24% average over all industries (**Figure 6-4**).

FIGURE 6-4

Foreign content share of global production of selected industries: 2007 and 2015



Note(s):
Foreign content share is the average of 64 countries and the rest of the world is 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.

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The pharmaceuticals industry, the next largest industry, has two main global value chains. For emerging and complex biologic vaccines and stem cell therapies, pharmaceutical companies generally locate closely with academic and medical R&D laboratories because these innovative products require close integration of R&D, testing, and manufacturing. For existing and mature technologies, such as small molecules and generics, companies do not need to locate near research laboratories because close integration of R&D and manufacturing is not as necessary (Donofrio and Whitefoot 2015). The foreign content share of the chemical and pharmaceuticals industries was 37% in 2015 (**Figure 6-4**).[2]

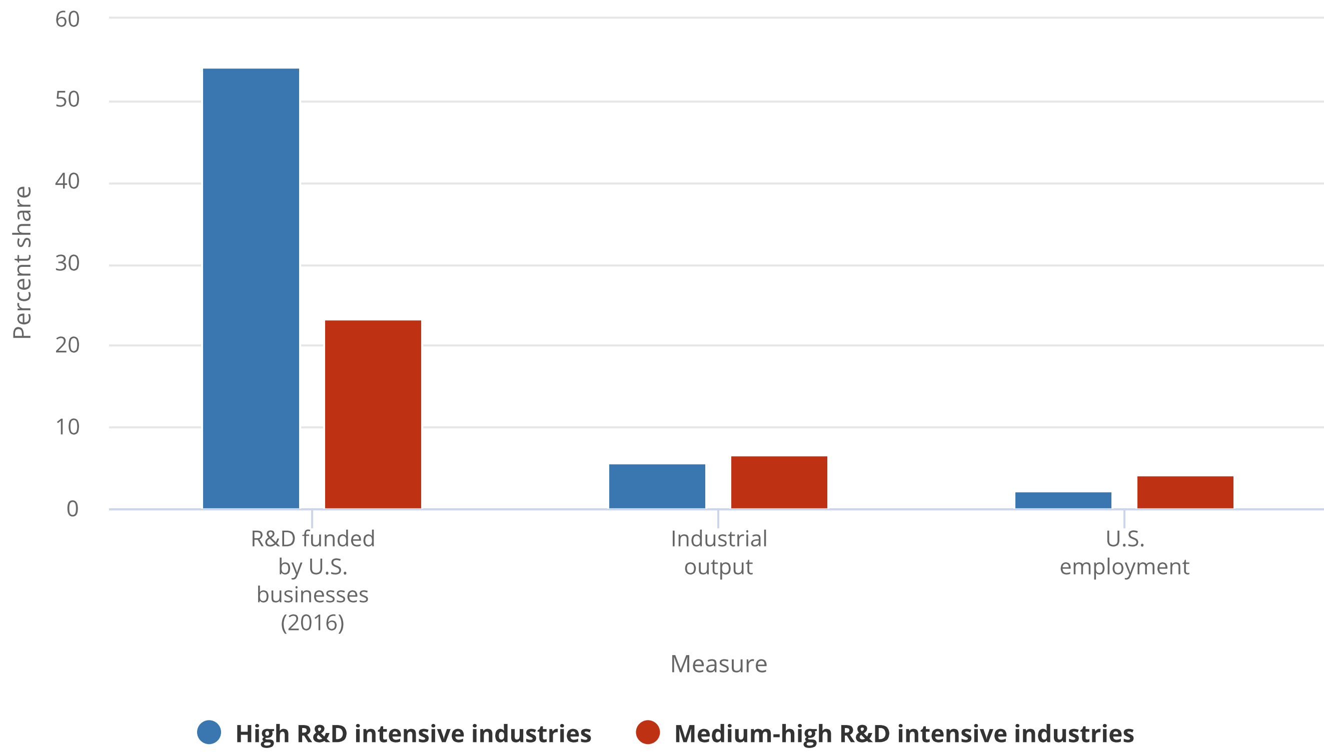
Global value chains are also present in other industries. The global aircraft industry is characterized by lead firms, including Airbus and Boeing, that outsource production of major subsystems, such as engines and avionics, to other companies, which in turn rely on subcontractors to provide smaller components. Global production chains of this industry are mainly located in developed countries (Turkina et al. 2016:1217).

High R&D Intensive Industry Trends in the United States

Although they account for a small share of U.S. industrial output (6%) and employment (2%), U.S. high R&D intensive industries fund a disproportionately large share—more than half—of R&D funded by U.S. businesses (**Figure 6-5**). In 2017, U.S. high R&D intensive industries employed 3.2 million people; the computer, electronic, and optical products industry is the largest employer with 1,156,000 employees followed by aircraft (752,000) and scientific R&D services (637,000) (**Figure 6-6**). Individuals with training in science, technology, engineering, and math who have an education level below a bachelor's degree, comprise 16% of the total workforce in U.S. high R&D intensive industries (see sidebar **The Skilled Technical Workforce in U.S. Knowledge- and Technology-Intensive Industries**).

FIGURE 6-5

U.S. KTI industry share of R&D funded by U.S. businesses, industry output, and industry employment: 2017



KTI = knowledge and technology intensive.

Note(s):

R&D consists of domestic funding by companies' own internal funds. Funds provided by other sources are not included. KTI industries include high R&D intensive and medium-high R&D intensive industries classified by the Organisation for Economic Co-operation and Development. High R&D intensive industries include aircraft; pharmaceuticals; computer, electronic, and optical products; scientific research and development; and software publishing. Medium-high R&D intensive industries include weapons and ammunition; motor vehicles; medical and dental instruments; machinery and equipment; chemicals and chemical products; electrical equipment; railroad, military vehicles, and transport; and IT and other information services. Output of industries is value added. U.S. employment does not include self-employed workers and those employed in private households. Coverage of some industries may vary among data sources because of differences in classification of industries.

Source(s):

National Center for Science and Engineering Statistics, National Science Foundation, Business R&D and Innovation Survey (BRDIS) (2016); Cenus Bureau, American Community Survey (ACS) (2018), public use microdata; Bureau of Economic Analysis, Gross Domestic Product by Industry.

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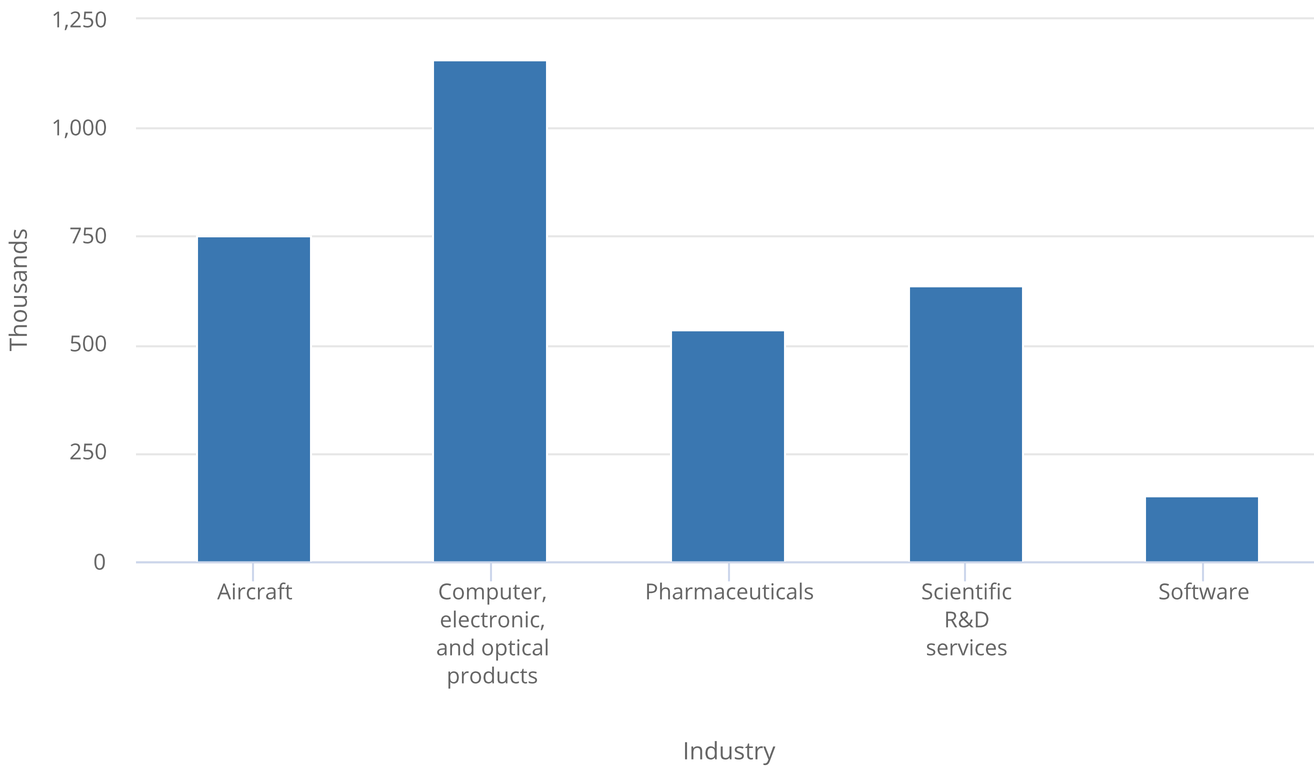
FIGURE 6-6

Employment in U.S. high R&D intensive industries: 2017



Note(s):
High R&D intensive industries include aircraft; pharmaceuticals; computer, electronic, and optical products; scientific research and development services; and software publishing classified by the Organisation for Economic Co-operation and Development.

Source(s):
Census Bureau, American Community Survey (ACS) (2018), public use microdata.

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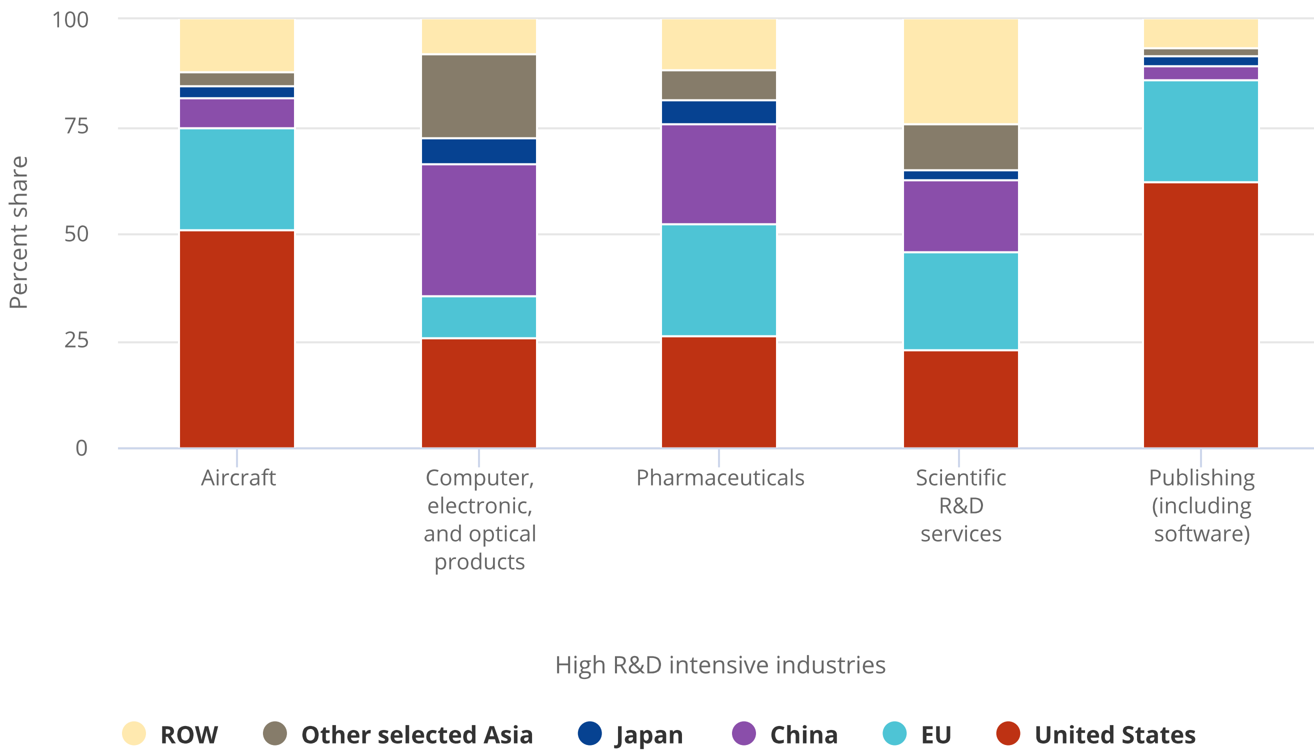
As the world's largest producer, the United States holds strong global positions in high R&D intensive industries. It is particularly strong in two of these industries—manufacturing of aircraft and publishing (including software) (**Figure 6-7**, Table S6-5, and Table S6-9). The U.S. produces from more than half to almost two thirds of global production of these industries.

FIGURE 6-7

High R&D intensive industries of selected regions, countries, or economies: 2018



EU = European Union; ROW = rest of world.

Note(s):

Output is measured on a value-added basis. Value added is the amount contributed by a country, firm, or other entity to the value of a good or service and excludes purchases of domestic and imported materials and inputs. Other selected Asia includes India, Indonesia, Malaysia, the Philippines, Singapore, South Korea, Taiwan, Thailand, and Vietnam. Data for software publishing are not available; the larger publishing industry, which includes software publishing, is used as a proxy for this industry.

Source(s):

IHS Markit, special tabulations (2019) of Comparative Industry Service. See Table S6-5 through Table S6-9.

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In the aircraft industry, the U.S. has consistently accounted for more than half of global production (Table S6-5). Much of the supply chain for the U.S. aircraft industry is globalized: for example, Boeing, a major producer, mostly specializes as a system integrator of major subsystems and components supplied by companies within and outside the United States (Turkina et al. 2016).

In the publishing (including software) industry, the United States has had a dominant position for the last decade and a half, producing more than half of global output (Table S6-9). A major driver has been the rise in U.S. business investment in software which more than doubled between 2002 and 2018 (from $152.5 billion to $380.0 billion) (BEA 2019).

In addition to industry-focused R&D, a growing industry is devoted to R&D services. The United States and the EU are the largest producers in the scientific R&D services industry in the world, each accounting for 23% of global activity (**Figure 6-7** and Table S6-8). This industry engages in original research to advance the state of knowledge and applications of research findings to improve products and processes in the areas of physical, engineering, and life sciences including electronics, biology, medicine, and physics, and in the areas of social sciences and humanities including economics, sociology, psychology, language, and behavior.

The United States is also a major global producer in the pharmaceuticals and the computer, electronic, and optical products industries. In the pharmaceuticals industry, the U.S. shares the top spot with the EU, each accounting for more than a quarter of global production (**Figure 6-7** and Table S6-6). In the computer, electronic, and optical products industry, the United States is the world's second-largest producer (26% global share), behind China (31% global share) (**Figure 6-7** and Table S6-7).

SIDEBAR

The Skilled Technical Workforce in U.S. Knowledge- and Technology-Intensive Industries

Knowledge- and technology-intensive (KTI) industries employ roughly 10 million people and account for 6% of the U.S. labor force (**Figure 6-5**, **Figure 6-6**, and **Figure 6-9**). These include people in different occupations with varying degrees of educational attainment, skill level, experience, and training. The *Indicators 2020* report "Science and Engineering Labor Force" provides a thorough analysis of the U.S. science and engineering (S&E) workforce.

One segment of the S&E workforce that performs important functions to support and advance science and technology is the skilled technical workforce (STW). The STW is composed of individuals who use science, technology, engineering, and mathematics knowledge and skills in their jobs and have a high school diploma, some college, an associate degree, or similar levels of qualification as their highest level of educational attainment.*

In 2017, about 486,000 individuals were employed as skilled technical workers in the U.S. high R&D intensive industries, comprising 16% of the total workforce in these industries (**Table 6-A**). Among the major high R&D intensive industries, aircraft (23%) and computer, electronic, and optical products (18%) had relatively high shares of skilled technical workers. Software publishing and scientific R&D services had smaller shares (less than 10%). Compared to the overall workforce of U.S. high R&D intensive industries, the STW employed in these industries has a lower share of women and Asians and a slightly higher share of Hispanics (**Figure 6-A**). The STW in these industries earned more compared to the overall STW in the United States (**Figure 6-B**).

In U.S. medium-high R&D intensive industries, employment in the STW was about 1.1 million in 2017, representing 19% of the total workforce, higher than that in the high R&D intensive industries (**Table 6-B**). Two industries—chemicals excluding pharmaceuticals (28%) and weapons (26%)—had relatively high shares of skilled technical workers. IT services had the lowest share (13%). The STW of U.S. medium-high R&D intensive industries has a significantly lower share of women and a slightly lower share of Asians (**Figure 6-C**). The median salary of the STW in these industries was higher than that of the STW of the entire U.S. labor force (**Figure 6-B**).

* For more information, see the STW section of *Indicators 2020* report "Science and Engineering Labor Force" and NSB (2019).

TABLE 6-A

Employment of the skilled technical workforce in U.S. high R&D intensive industries: 2017

(Thousands of employees and percent share)

Industry	Total	STW	STW share (%)
High R&D intensive industries	3,044.7	486.4	16.0
Aircraft	717.6	162.7	22.7
Computer, electronic, and optical products	1,097.2	193.6	17.6
Pharmaceuticals	506.5	70.5	13.9
Scientific R&D services	582.2	46.5	8.0
Software	141.3	13.2	9.3

STW = skilled technical workforce.

Note(s):

Skilled technical workers are in occupations that employ significant levels of S&E expertise and technical knowledge and whose educational attainment is less than a bachelor's degree. Employment figures are for those aged 25 and older and do not include those employed in military occupations. High R&D intensive industries are classified by the Organisation for Economic Co-operation and Development.

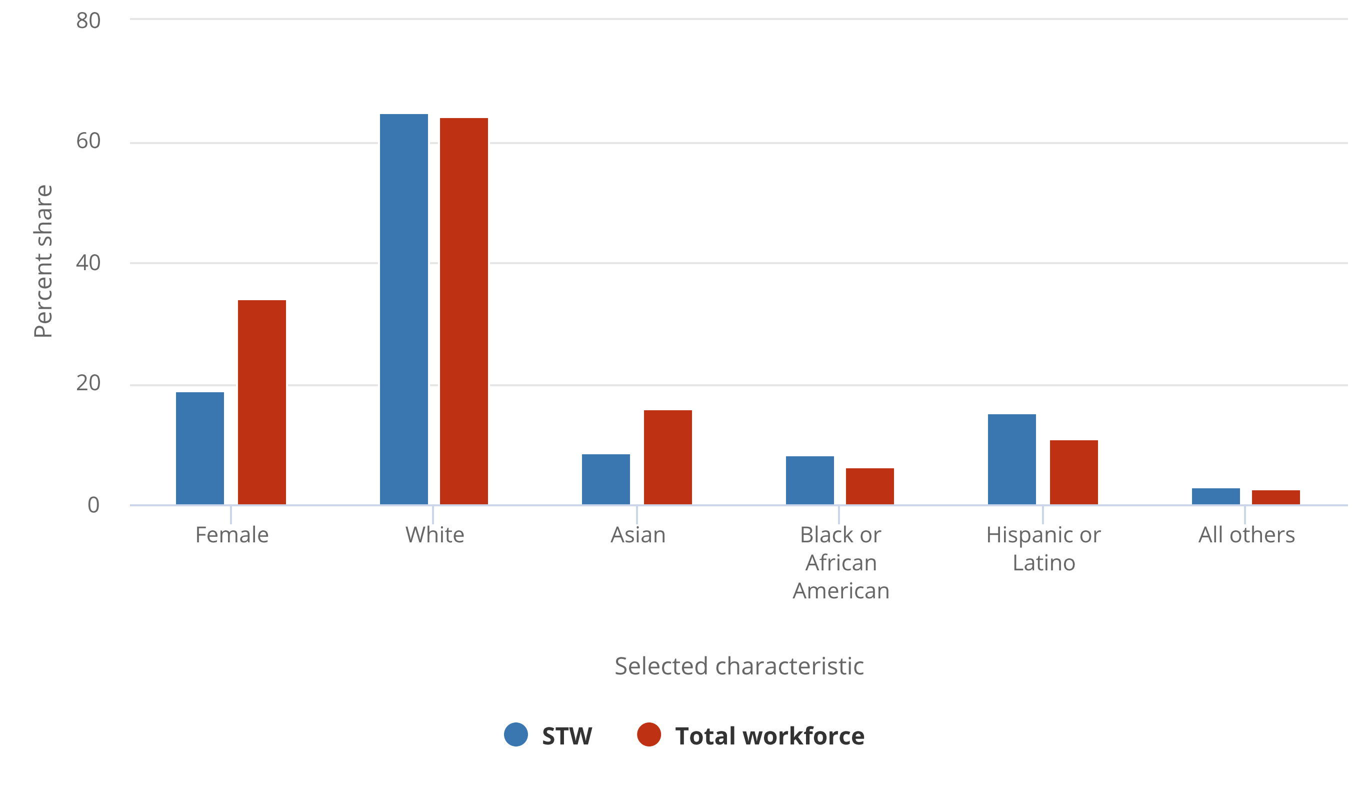
Source(s):

Census Bureau, American Community Survey (ACS) (2018), public use microdata.

Science and Engineering Indicators

FIGURE 6-A

Demographic characteristics of skilled technical and total workforce of U.S. high R&D intensive industries: 2017



STW = skilled technical workforce.

Note(s):

Skilled technical workers are in occupations that employ significant levels of S&E expertise and technical knowledge and whose educational attainment is less than a bachelor's degree. Employment figures are for those aged 25 and older and do not include those employed in military occupations. High R&D intensive industries consist of aircraft; pharmaceuticals; computer, electronic, and optical products; scientific research and development; and software publishing and are classified by the Organisation for Economic Cooperation and Development. Hispanic may be any race; race categories exclude Hispanic origin. All others includes American Indians, Alaska Natives, Native Hawaiians, other races, and multiple races. The sum of ethnicities may not add to 100 because of rounding.

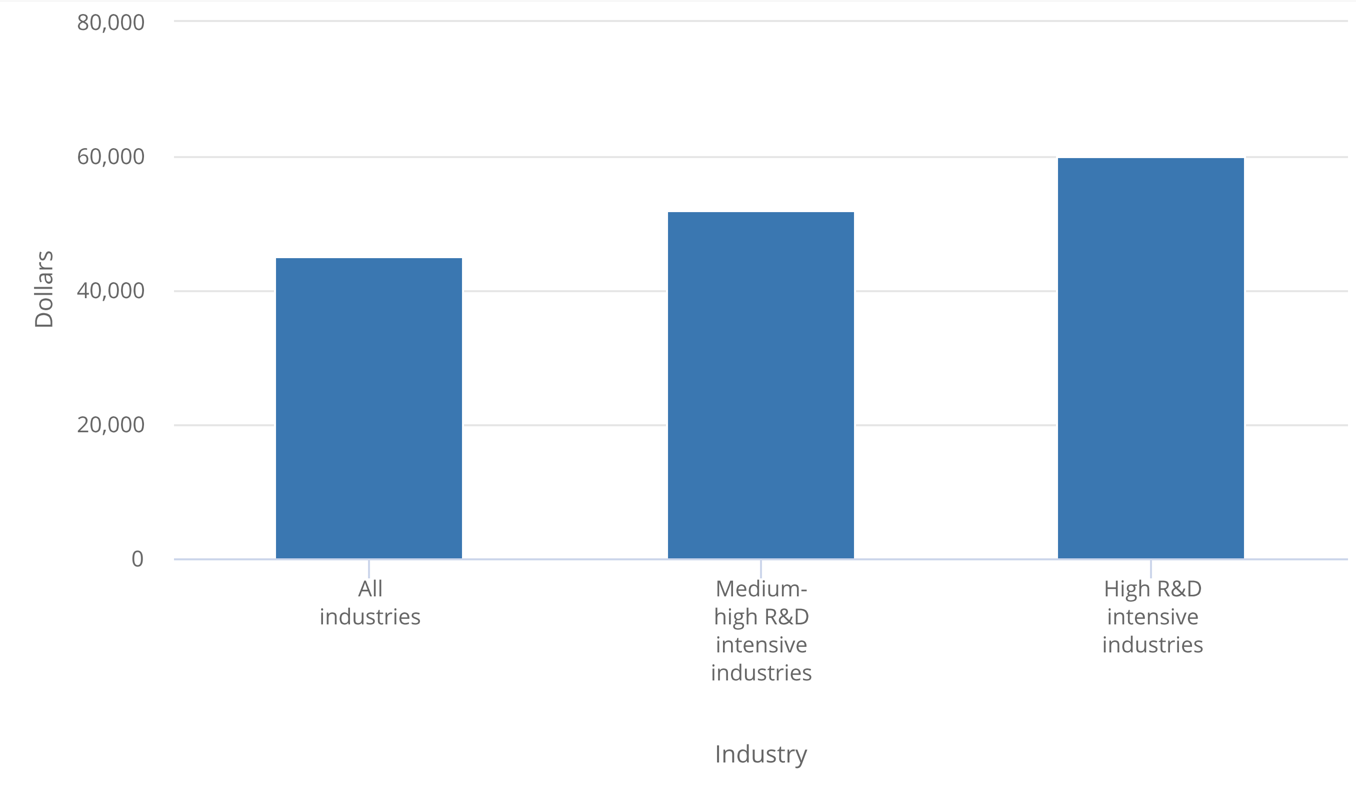
Source(s):

Census Bureau, American Community Survey (ACS) (2018), public use microdata.

Science and Engineering Indicators

FIGURE 6-B

Median salary of STW of U.S. KTI industries: 2017



KTI = knowledge and technology intensive; STW = skilled technical workforce.

Note(s):

Skilled technical workers are in occupations that employ significant levels of S&E expertise and technical knowledge and whose educational attainment is less than a bachelor's degree. Employment figures are for those aged 25 and older and do not include those employed in military occupations. KTI industries include high R&D intensive and medium-high R&D intensive industries classified by the Organisation for Economic Co-operation and Development. High R&D intensive industries include aircraft; pharmaceuticals; computer, electronic, and optical products; scientific research and development services; and software publishing. Medium-high R&D intensive industries include weapons and ammunition; motor vehicles; medical and dental instruments; machinery and equipment; chemicals and chemical products; electrical equipment; railroad, military vehicles, and transport; and IT and other information services. Industries are defined by the North American Industry Classification System (NAICS). The American Community Survey does not cover employment among self-employed workers and employment in private households (NAICS 814). In the employment total for agriculture, forestry, fishing, and hunting, only the following industries are included: logging (NAICS 1133), support activities for crop production (NAICS 1151), and support activities for animal production (NAICS 1152). As a result, the data do not represent total U.S. employment.

Source(s):

Census Bureau, American Community Survey (ACS) (2018), public use microdata.

Science and Engineering Indicators

TABLE 6-B

Employment of the skilled technical workforce in U.S. medium-high R&D intensive industries: 2017

(Thousands of employees and percent share)

Industry	Total	STW	STW share (%)
Medium-high R&D intensive industries	5,832.5	1,084.6	18.6
Chemicals excluding pharmaceuticals	769.0	212.8	27.7
Electrical equipment	401.1	79.1	19.7
IT services	2,659.5	355.6	13.4
Machinery and equipment	622.9	149.1	23.9
Motor vehicles	1,277.6	265.8	20.8
Railroad and other transportation	62.4	11.9	19.1
Weapons	40.0	10.3	25.8

IT = information technology; STW = skilled technical workforce.

Note(s):

Skilled technical workers are in occupations that employ significant levels of S&E expertise and technical knowledge and whose educational attainment is less than a bachelor's degree. Employment figures are for those aged 25 and older and do not include those employed in military occupations. Medium-high R&D intensive industries are classified by the Organisation for Economic Co-operation and Development.

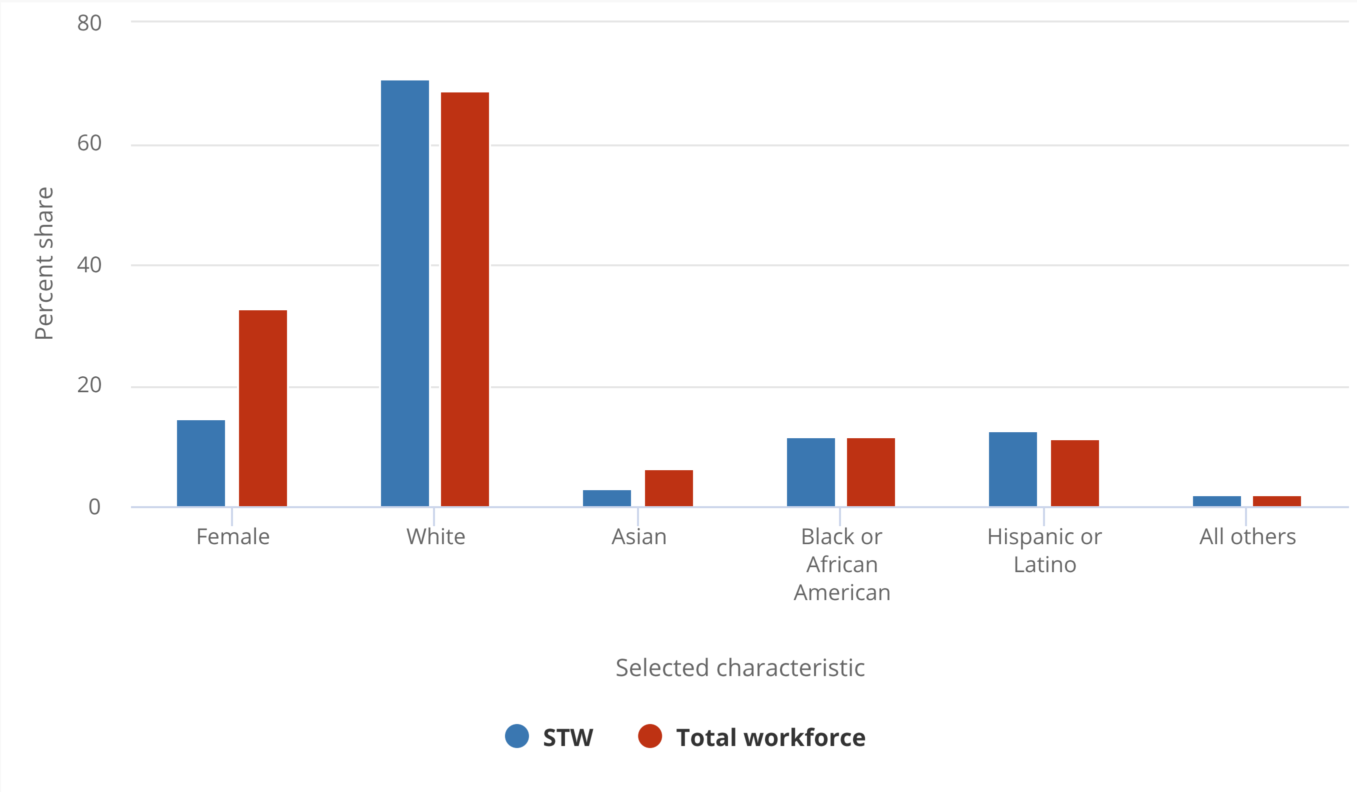
Source(s):

Census Bureau, American Community Survey (ACS) (2018), public use microdata.

Science and Engineering Indicators

FIGURE 6-C

Demographic characteristics of skilled technical and total workforce of U.S. medium-high R&D intensive industries: 2017



STW = skilled technical workforce.

Note(s):

Skilled technical workers are in occupations that employ significant levels of S&E expertise and technical knowledge and whose educational attainment is less than a bachelor's degree. Employment figures are for those aged 25 and older and do not include those employed in military occupations. Medium-high R&D intensive industries include weapons and ammunition; motor vehicles; medical and dental instruments; machinery and equipment; chemicals and chemical products; electrical equipment; railroad, military vehicles, and transport; and IT and other information services and are classified by the Organisation for Economic Co-operation and Development. Data not available for medical and dental instruments. Hispanic may be any race; race categories exclude Hispanic origin. All others includes American Indians, Alaska Natives, Native Hawaiians, other races, and multiple races. The sum of ethnicities may not add to 100 because of rounding.

Source(s):

Census Bureau, American Community Survey (ACS) (2018), public use microdata.

Science and Engineering Indicators

High R&D Intensive Industry Trends in China

China and the EU are tied as the second-largest producers in high R&D intensive industries with China's global share growing and that of the EU in decline (**Figure 6-3** and Table S6-3). China's global share has grown rapidly from 5.6% in 2002 to 20.6% in 2018 (Table S6-3), driven by growth in many high R&D intensive industries. China has made the largest gain in the computer, electronic, and optical products industry; China's output in this industry has grown nearly nine-fold since 2002, becoming and remaining the world's largest producer since 2014 (Table S6-7). In the computer industry, China has made impressive progress in its supercomputing ability over the last few years, an area that it had little presence in a decade ago (see sidebar **China's Progress in Supercomputers**). Although Chinese semiconductor companies have gained global market share, China remains reliant on semiconductors supplied by foreign firms for most of its production of smartphones and other electronic products (PwC 2017).

China is an important part of "Factory Asia"—the electronics goods production network centered in East Asia (WTO and IDE-JETRO 2011). China plays a central role in this network as the major location of final assembly and as the largest importer and exporter of electronic components. 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 that is required for many electronic products that have short development cycles (Donofrio and Whitefoot 2015:26).

Four Asian economies—Japan, Singapore, South Korea, and Taiwan—are major producers of components and finished electronic goods, and are closely integrated with China. These four Asian economies are major importers of components from China. According to the OECD's Trade in Value Added data, China comprised 30% or more of Japan, South Korea, and Taiwan's imports of computer, electronic, and optical products, and 17% of Singapore's imports in this industry. South Korea and Taiwan are major exporters of components to China (Frederick and Lee 2017:24). In 2015, these two economies each accounted for about 25% of China's imports of computer, electronic, and optical products according to the OECD's Trade in Value Added database.

China has also markedly increased its global share in the pharmaceutical and scientific R&D service industries, becoming the third-largest global producer in pharmaceuticals and in scientific R&D services (**Figure 6-7**, Table S6-6, and Table S6-8). According to Cao (2014) and Hsu (2015), the rapidly expanding middle class, reform of China's health care system, and increasing demand for health care has fueled the rapid expansion of China's pharmaceuticals industry. 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). In the aircraft industry, China's rapid growth continued, particularly over the last 5 years, albeit from a low base (Table S6-5).

SIDEBAR

China's Progress in Supercomputers

The TOP500, an organization composed of computer scientists and industry specialists, has been tracking the world's most powerful and fastest-performing supercomputers since 1993. The TOP500 provides a semiannual update of the world's top 500 supercomputers, including information on the country of origin, performance, type of application, and technology. According to the TOP500's June 2019 data, two supercomputers in China were ranked third and fourth in the world, giving China two slots in the top 10 list. The world's third-ranked computer is the 93-petaflop Sunway TaihuLight supercomputer at the National Supercomputing Center in Wuxi.* The fourth-ranked computer is the 61-petaflop Tianhe-2A (MilkyWay-2A) in the National Supercomputer Center in Guangzhou. The United States continued to have the largest share of supercomputers in the TOP10, with five in the 2019 list.

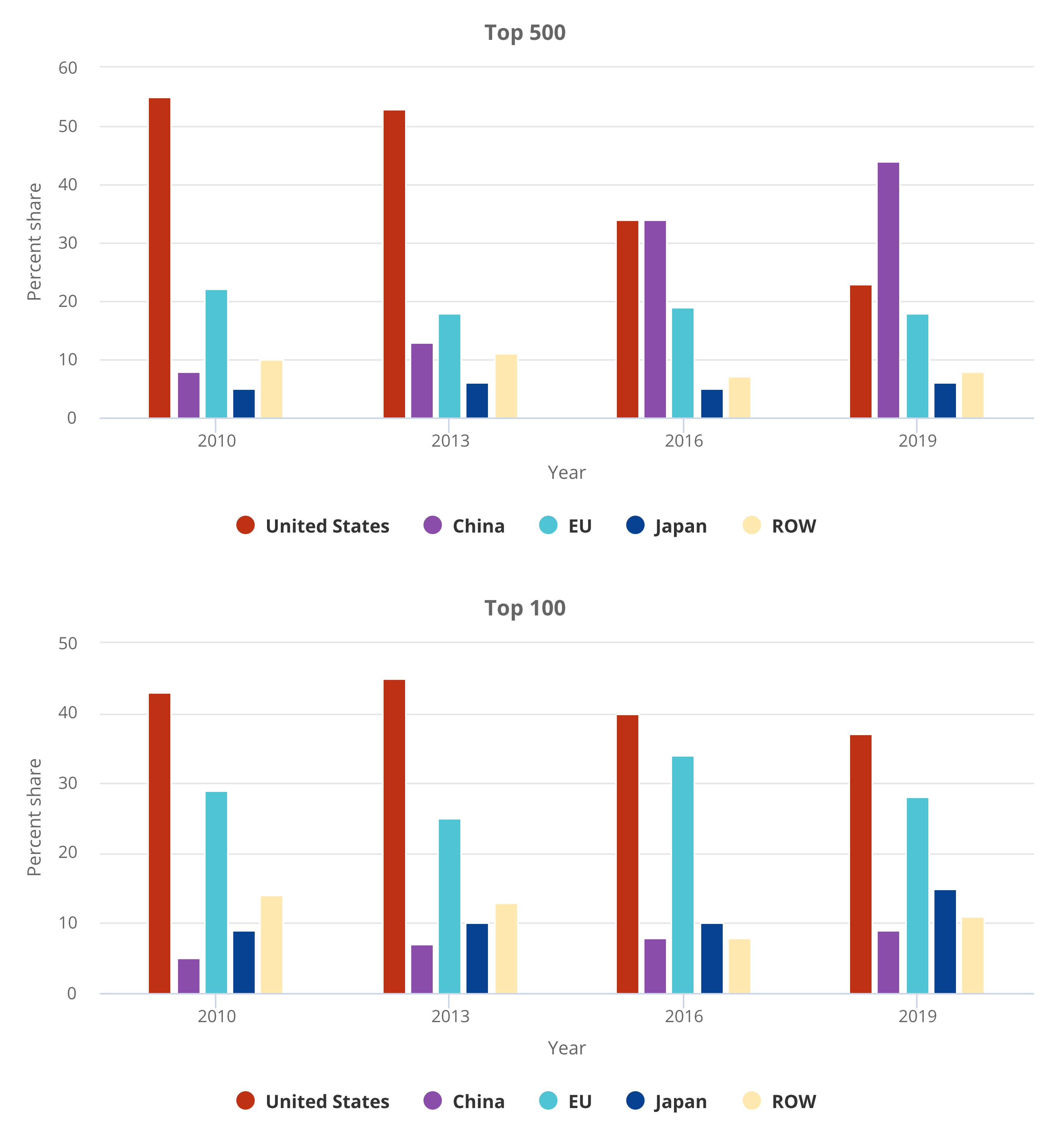
China has become dominant in the TOP500 list in a remarkably short time with its share jumping from 13% in 2013 to 44% in 2019 (**Figure 6-D**). The U.S. share has fallen sharply from 53% to 23% in the same period (**Figure 6-D**). Although its achievements are impressive, China's dominance is concentrated in the bottom half of the TOP500 list that largely consists of less advanced supercomputers that conduct routine activities such as running Web-based or back-office applications (Feldman 2017). China's median ranking in the TOP500 (the middle of China's ranked supercomputers) was 306. Although it has a much smaller share of the TOP500 list than China, the median ranking of the United States is 157.

The United States remains dominant in the TOP100 list that typically are the most sophisticated supercomputers used in scientific research (**Figure 6-D**). These supercomputers conduct scientific activities, such as processing and simulating quantum mechanics, weather forecasting, climate research, oil and gas exploration, and molecular modeling and physical simulations. China's share (9%) is far smaller than the United States, and it has made far less progress increasing its presence in the TOP100 list compared to the TOP500 (**Figure 6-D**).

* One petaflop is equivalent to one thousand million million (10^{15}) floating-point operations per second.

FIGURE 6-D

Top-ranked supercomputers, by region, country, or economy: 2010–19



EU = European Union; ROW = rest of world.

Source(s):
TOP500, May 2019 and November 2016, 2013, and 2010 reports.

Science and Engineering Indicators

High R&D Intensive Industry Trends in the EU and Japan

The EU's global share of high R&D intensive output declined from 26% in 2008 to 22% in 2011 and fluctuated between 19% and 21% since 2011 (**Figure 6-3**). The EU ties with the United States as the world's largest producer in pharmaceuticals (26% global share) and scientific R&D services (23% global share) (**Figure 6-7**, Table S6-6, and Table S6-8). The EU is the second-largest producer in aircraft (24% global share) and publishing (including software) (24%) (Table S6-5 and Table S6-9). The EU's production is much lower than the United States and China in computer, electronic, and optical products (**Figure 6-7** and Table S6-7).

Japan's global share of high R&D intensive industries fell from 9% in 2010 to 5% in 2018 (**Figure 6-3** and Table S6-3). The computer, electronic, and optical products industry had the steepest decline, falling from 14% to 6% during this period (Table S6-7). Japan's deep decline in this and other high R&D intensive industries coincides with slow labor force and economic growth as well as the transfer of production to China and other countries.[3]

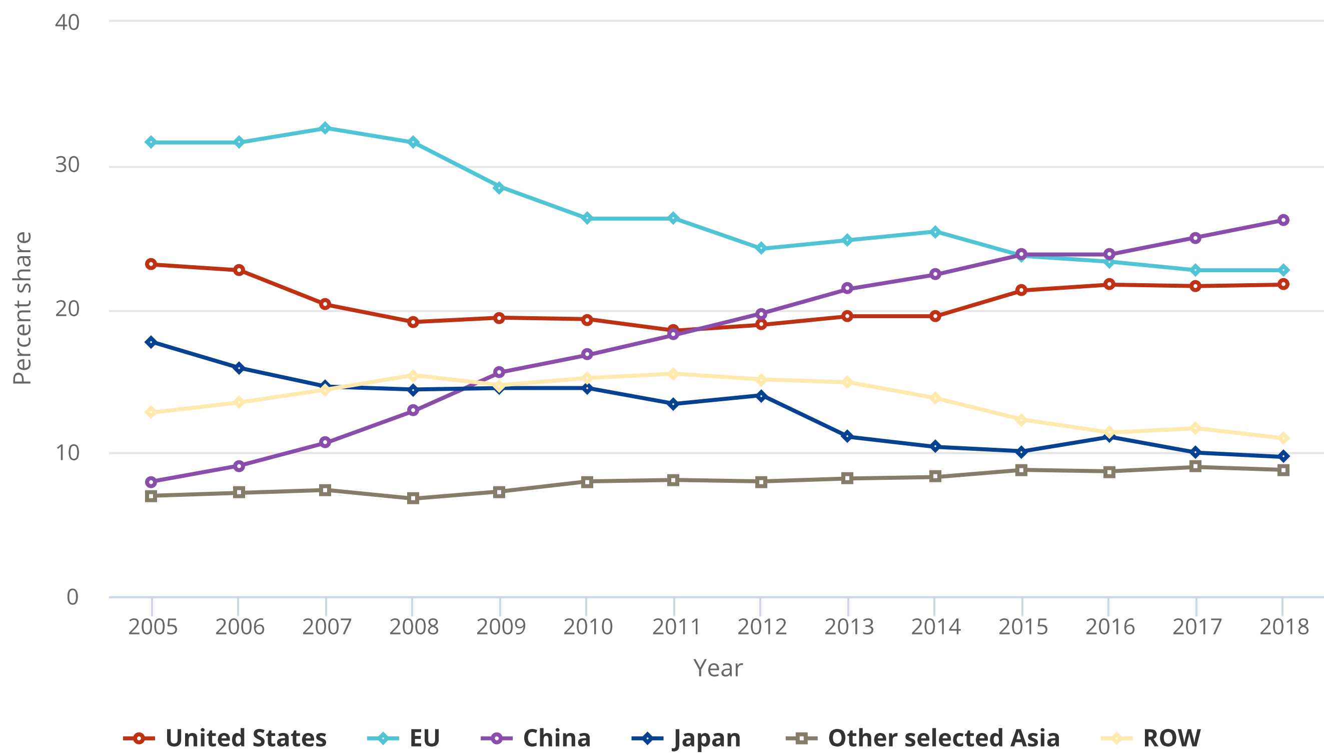
The depreciation of the euro and yen between 2013 and 2018 may have understated to some degree the performance of the EU and Japan's high R&D intensive industries (see **Technical Appendix** for more information).

Global Trends in Medium-High R&D Intensive Industries

The United States produces a smaller share of global output in medium-high R&D intensive industries compared to high R&D intensive industries. China is the world's largest producer in these industries (26% of global output) followed by the EU and the United States (22%–23% global share) (**Figure 6-8** and Table S6-4). Between 2002 and 2018, China's output grew rapidly, expanding its global share from 7% to 26%.

FIGURE 6-8

Output of medium-high R&D intensive industries for selected regions, countries, or economies: 2005–18



EU = European Union; ROW = rest of world.

Note(s):

Output is measured on a value-added basis. Value added is the amount contributed by a country, firm, or other entity to the value of a good or service and excludes purchases of domestic and imported materials and inputs. Medium-high R&D intensive industries include weapons and ammunition; motor vehicles; medical and dental instruments; machinery and equipment; chemicals and chemical products; electrical equipment; railroad, military vehicles, and transport; and IT and other information services classified by the Organisation for Economic Co-operation and Development. Data on medical and dental instruments are not available. Other selected Asia includes India, Indonesia, Malaysia, the Philippines, Singapore, South Korea, Taiwan, Thailand, and Vietnam. See Table S6-4.

Source(s):

IHS Markit, special tabulations (2019) of Comparative Industry Service.

Science and Engineering Indicators

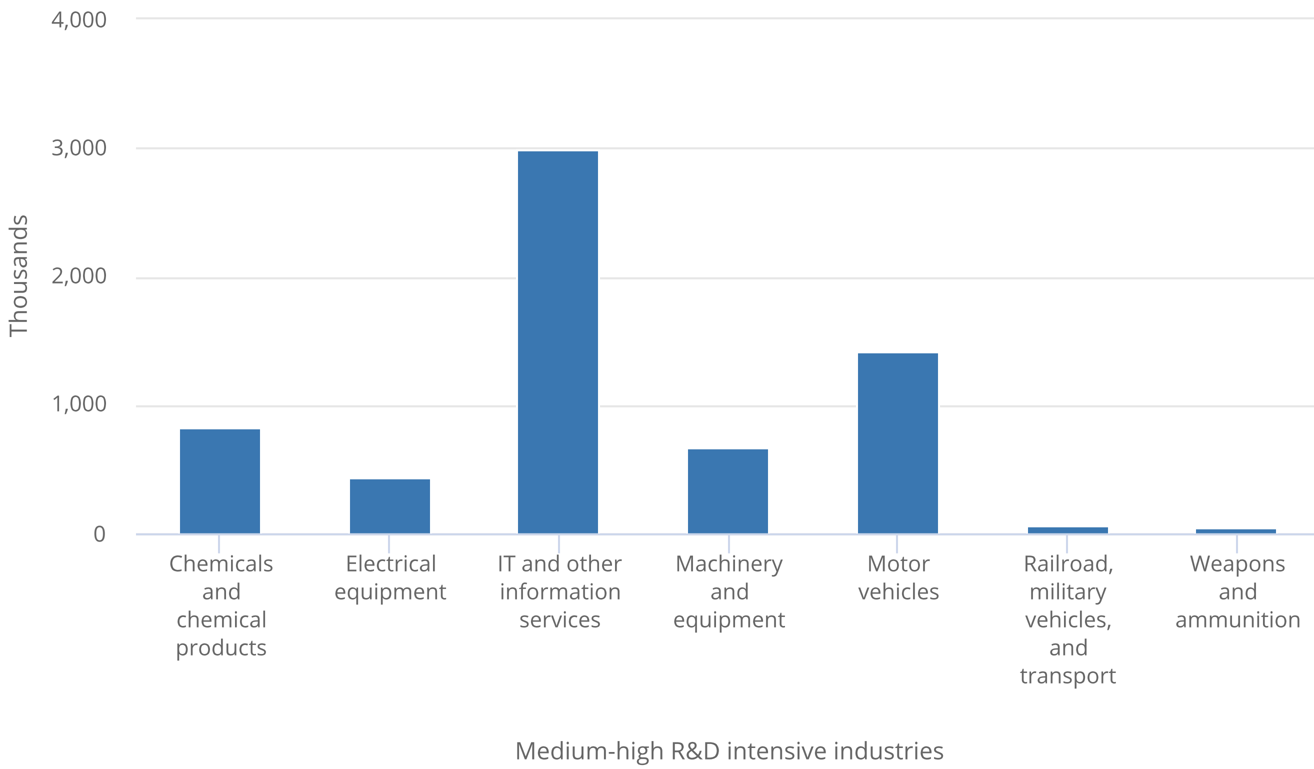
Medium-high R&D industries have global and often complex value chains, a characteristic shared with high R&D intensive industries. However, production activities are generally located closer to the final market than consumer electronics and other information and communication technologies (ICT) industries that have lightweight products (Donofrio and Whitefoot 2015:25). Transportation costs are high in many of these industries because the final products and major components are often large and heavy, particularly automobiles, large appliances, and heavy equipment. For example, in the motor vehicles and parts industry, the manufacturing facilities of three major global automakers—General Motors, Toyota, and Volkswagen—are widely dispersed and clustered in the regions or countries of their final markets.

Medium-High R&D Intensive Industry Trends in the United States

Although the medium-high R&D intensive industries account for a small share of U.S. industrial output and employment, they fund nearly one-quarter of R&D funded by U.S. businesses (**Figure 6-5**). These industries employ 6.5 million people, 4% of U.S. employment (**Figure 6-9**). IT services is the largest employer (3.0 million people), followed by motor vehicles (1.4 million). Individuals with training in science, technology, engineering, and math who have an education level below a bachelor's degree, comprise nearly one-fifth of the total workforce (see sidebar **The Skilled Technical Workforce in U.S. Knowledge- and Technology-Intensive Industries**).

FIGURE 6-9

Employment in U.S. medium-high R&D intensive industries: 2017



Note(s):

Medium-high R&D intensive industries include weapons and ammunition; motor vehicles; medical and dental instruments; machinery and equipment; chemicals and chemical products; electrical equipment; railroad, military vehicles, and transport; and IT and other information services classified by the Organisation for Economic Co-operation and Development. Data are not available for medical and dental instruments.

Source(s):

Census Bureau, American Community Survey (ACS) (2018), public use microdata.

Science and Engineering Indicators

The United States is the world's largest producer of IT services (**Table 6-2** and Table S6-16). The United States is the second-largest producer in chemicals excluding pharmaceuticals (21% global share) and ties with the EU as the second-largest producer in railroad and other transport industry (15% global share) (Table S6-13 and Table S6-15).

TABLE 6-2

Medium-high R&D intensive industries of selected regions, countries, or economies: 2018

(Percent)

Medium-high R&D intensive industries	Global output ($billions)	United States	EU	China	Japan	Other selected Asia	ROW
Chemicals excluding pharmaceuticals	1,026.5	21.1	17.0	29.1	5.6	10.7	16.6
Electrical equipment	655.7	9.4	17.6	46.2	10.2	8.4	8.2
IT services	1,621.8	36.9	26.6	10.1	7.5	8.2	10.6
Machinery and equipment	1,195.2	15.0	24.2	33.3	13.5	6.5	7.6
Motor vehicles	1,109.7	15.2	24.4	27.2	13.0	10.0	10.2
Railroad and other transport	119.9	15.0	15.3	37.0	4.2	14.3	14.2
Weapons	50.1	18.2	21.0	10.1	1.4	9.9	39.5

EU = European Union; IT = information technology; ROW = rest of world.

Note(s):
Output is measured on a value-added basis. Value-added is the amount contributed by a country, firm, or other entity to the value of a good or service and excludes purchases of domestic and imported materials and inputs. Medium-high R&D intensive industries include weapons and ammunition; motor vehicles; medical and dental instruments; machinery and equipment; chemicals and chemical products; electrical equipment; railroad, military vehicles, and transport; and IT and other information services classified by the Organisation for Economic Co-operation and Development. Data are not available for medical and dental instruments. World total does not include all countries and economies due to limitations in data availability. Other selected Asia includes India, Indonesia, Malaysia, the Philippines, Singapore, South Korea, Taiwan, Thailand, and Vietnam. See Table S6-10 through Table S6-16.

Source(s):
IHS Markit, special tabulations of Comparative Industry Service.

Science and Engineering Indicators

Medium-High R&D Intensive Industry Trends in China

China is the world's largest producer of chemicals excluding pharmaceuticals, electrical equipment, motor vehicles, other machinery and equipment, and railroad and other transport (**Table 6-2**, and Table S6-11 through Table S6-15). These industries grew very rapidly over the last decade. Output of electrical equipment grew by three-fold with China's global share doubling from 23% to 46%. China's global share also doubled in other machinery and equipment to reach 33% in 2018. China surpassed the EU in 2017 to become the world's larger producer in motor vehicles (27% global share).

China's growth in many of these industries coincides with a rapid expansion of its exports of medium-high R&D intensive goods. These more than doubled over the last decade (see “Trade in Medium-High R&D Intensive Goods”).

The EU, the second-largest producer of medium-high R&D intensive industries, saw its global share fall from 26% to 23% between 2010 and 2018 (**Figure 6-8** and Table S6-4). The EU is the second-largest producer of motor vehicles (24% global share) closely behind China (**Table 6-2** and Table S6-11). The EU is also the second-largest producer of IT services (27% global share) significantly below the United States (37% global share) (Table S6-16). Japan is the fourth largest producer in motor vehicles, closely behind the United States (13% versus 15%) (**Table 6-2** and Table S6-11).

Beyond KTI Industries: The Case of Agriculture

Science and technology are also used outside of KTI industries. Such industries may incorporate advanced technology in their services and delivery of their services, use advanced manufacturing techniques, or incorporate technologically advanced inputs in manufacturing. Agriculture, though not classified as a KTI, is an intensive user of advanced and science-based technologies.

The introduction of many technologies, including biotechnology, has fueled productivity growth in U.S. agriculture (Wang et al. 2015:38-45). Agriculture productivity, as measured by total factor productivity, grew at an annualized average rate of 1.5% between 1948 and 2015. Output more than doubled with only slight growth in use of inputs, including labor and capital, allowing the U.S. agricultural sector to feed far more people today while using less farmland than six decades ago (Wang et al. 2015:5).

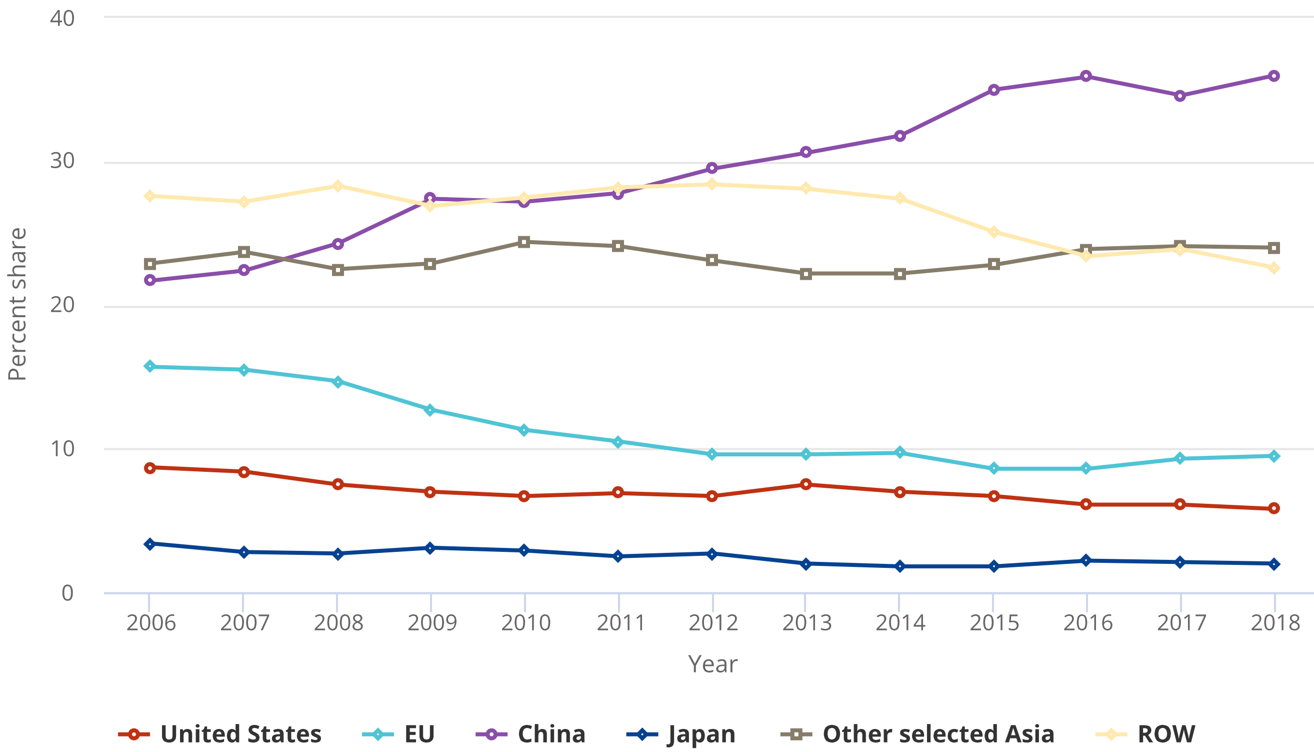
U.S. agriculture has benefited from R&D funding provided by the U.S. Department of Agriculture, which was $2.4 billion in FY 2017 (NCSES 2019). U.S. universities received $824 million from the U.S. Department of Agriculture in FY 2017 to perform R&D. U.S. agriculture has also made technological progress with basic science that was not directed at agriculture, such as recombinant DNA technology (Wang et al. 2015:39).

U.S. agriculture has also benefited from R&D performed by companies classified outside of the agricultural sector. For example, the pharmaceutical and biotechnology industries performed a total of $81 billion in R&D in 2016 (NCSES 2016). Newer and emerging technologies, including big data, cloud computing, robotics, and drones, are being widely adopted in agriculture in the United States and other countries (Scott, Chen, and Cui 2018).

Although the U.S. agricultural sector is highly productive and an intensive user of technology, China is the world's largest agriculture producer, accounting for more than one-third of the $2.8 trillion total global value-added output. The EU (10% global share) and the United States (6% global share) are the next largest producers (**Figure 6-10**). Between 2006 and 2018, the rapid growth of China's agriculture industry resulted in its global share jumping from 22% to 36%—similar to its trend in the high and medium-high R&D intensive industries (**Figure 6-10**). The shares of the United States, the EU, and Japan all declined during this period.

FIGURE 6-10

Output of agriculture industry for selected regions, countries, or economies: 2006–18



EU = European Union; ROW = rest of world.

Note(s):

Output of agriculture includes forestry and fisheries. Output is measured on a value-added basis. Value added is the amount contributed by a country, firm, or other entity to the value of a good or service and excludes purchases of domestic and imported materials and inputs. China includes Hong Kong. Other selected Asia includes India, Indonesia, Malaysia, the Philippines, Singapore, South Korea, Taiwan, Thailand, and Vietnam.

Source(s):

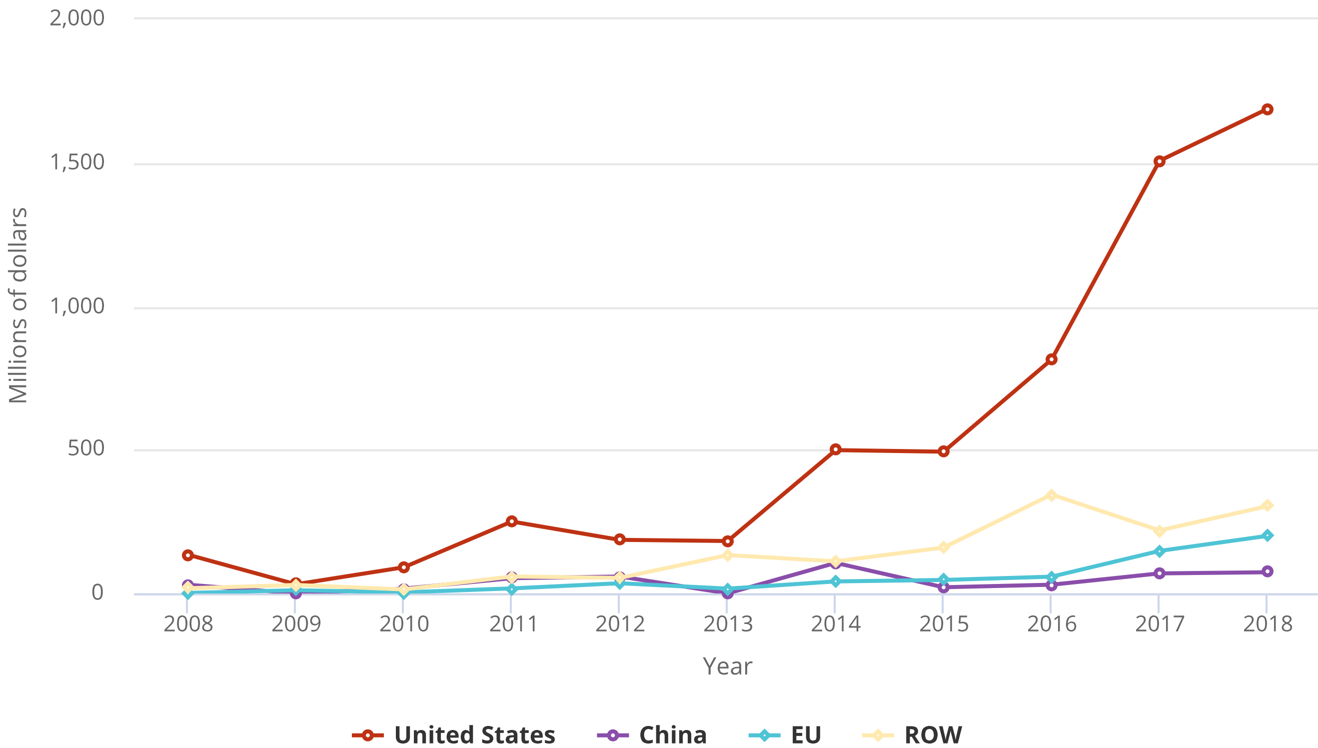
Oxford Economics, special tabulations (2019) of Global Industry Databank.

Science and Engineering Indicators

Venture capital investment, an indicator of the commercialization of new technologies, has been increasing rapidly in start-up companies in agricultural technologies, including wireless sensors, remote controlled irrigation systems, and software to optimize planting (**Figure 6-11**). Global venture capital investment for agricultural technologies jumped from less than $200 million in 2008 to $2 billion in 2018, with the majority of the funds being invested in the United States.

FIGURE 6-11

Venture capital investment in agricultural technology, by selected region, country, or economy: 2008–18



EU = European Union; ROW = rest of world.

Source(s):
Pitchbook, venture capital and private equity database, accessed October 1, 2019.

Science and Engineering Indicators

Global Trade in High and Medium-High R&D Intensive Products

Exported goods and services to other countries are an indicator of a country's economic success in the global market because exports capture the country's products that compete in the world market. The production of many goods, including electronics and automobiles, has become fragmented and disbursed across many countries. A significant volume of world trade is in unfinished intermediate goods that are exported to other countries for further production. These other countries supply additional inputs or perform final assembly before exporting the finished good. Conventional measures of trade are an imperfect measure of production in global value chains, including high and medium-high R&D intensive goods. Conventional trade measures credit the entire value of the finished product to the country that exported the finished product, which exaggerates the contribution of the final exporting country, and do not credit the value to countries that provided intermediate goods to produce the finished good.

This section briefly examines trade in high and medium-high R&D intensive goods for the United States and other major economies as measured in conventional trade data. It then examines trade in value-added data for certain high R&D intensive goods for which data are available—computer, electronic, and optical products industry (see sidebar **Trade in Value Added of the Computer, Electronic, and Optical Products Industry**).

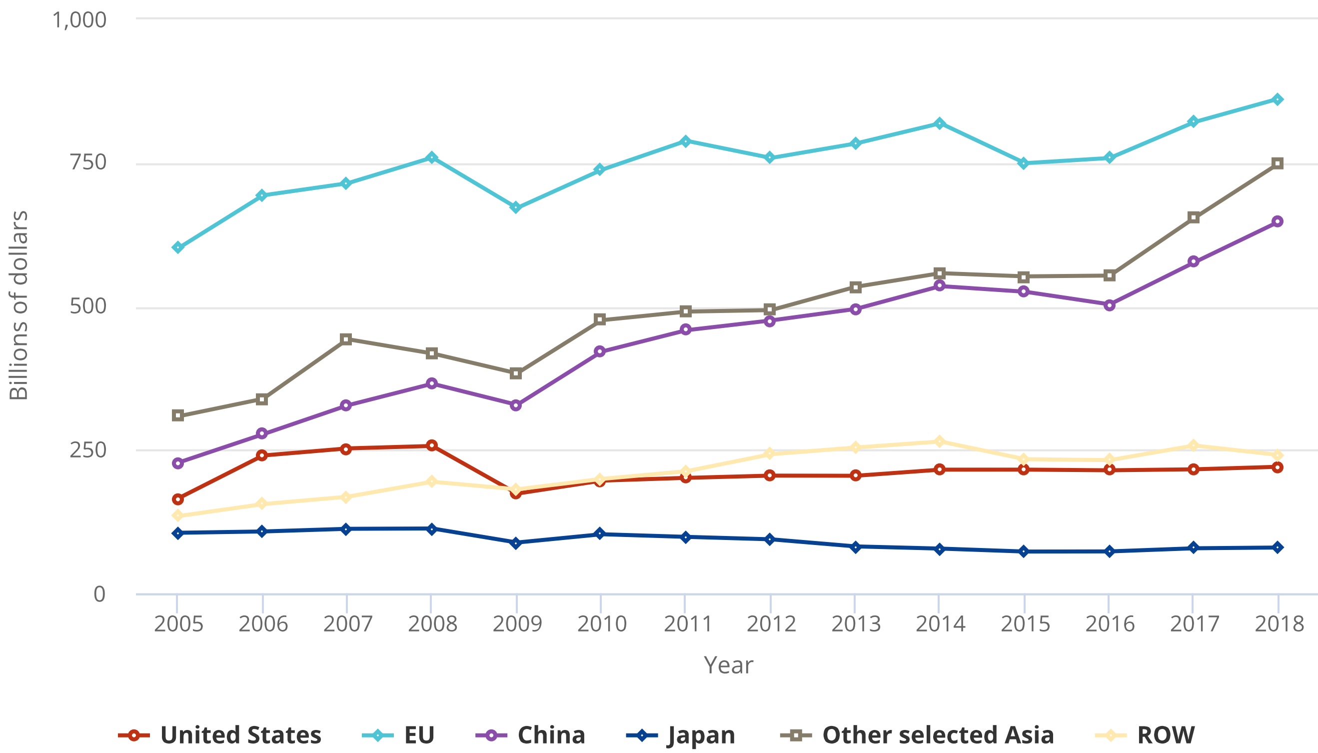
Value-added trade data are a more accurate measure of goods produced in global value chains. The data show that the United States has a smaller trade deficit and higher exports than on a conventional basis in electronic goods, which are part of high R&D intensive products.

Trade in High R&D Intensive Products

Global exports of high R&D intensive products—aircraft; computer, electronic, and optical products; and pharmaceuticals—were $2.8 trillion in 2018; the United States makes up a relatively small global share among the major economies (**Figure 6-12** and Table S6-19). Over the last decade, the growth trend of U.S. exports has been uneven with a sharp decline in 2009 before levelling off at a lower level. The U.S. global share declined from 12% to 8% during this period (**Figure 6-12** and Table S6-19). The U.S. trade deficit has substantially widened by slightly more than $200 billion over the last decade (**Figure 6-13** and Table S6-19). The United States has the largest trade deficit in high R&D intensive products among major economies ($304 billion), 38% larger than the value of its exports (**Figure 6-13** and Table S6-19).

FIGURE 6-12

Exports of high R&D intensive products, by selected region, country, or economy: 2005–18



EU = European Union; ROW = rest of world.

Note(s):

High R&D intensive products include aircraft; pharmaceuticals; and computer, electronic, and optical products classified by the Organisation for Economic Co-operation and Development. China includes Hong Kong. China data excludes bilateral flows between mainland China and Hong Kong. Other selected Asia includes India Indonesia, Malaysia, the Philippines, Singapore, South Korea, Taiwan, Thailand, and Vietnam. See Table S6-19.

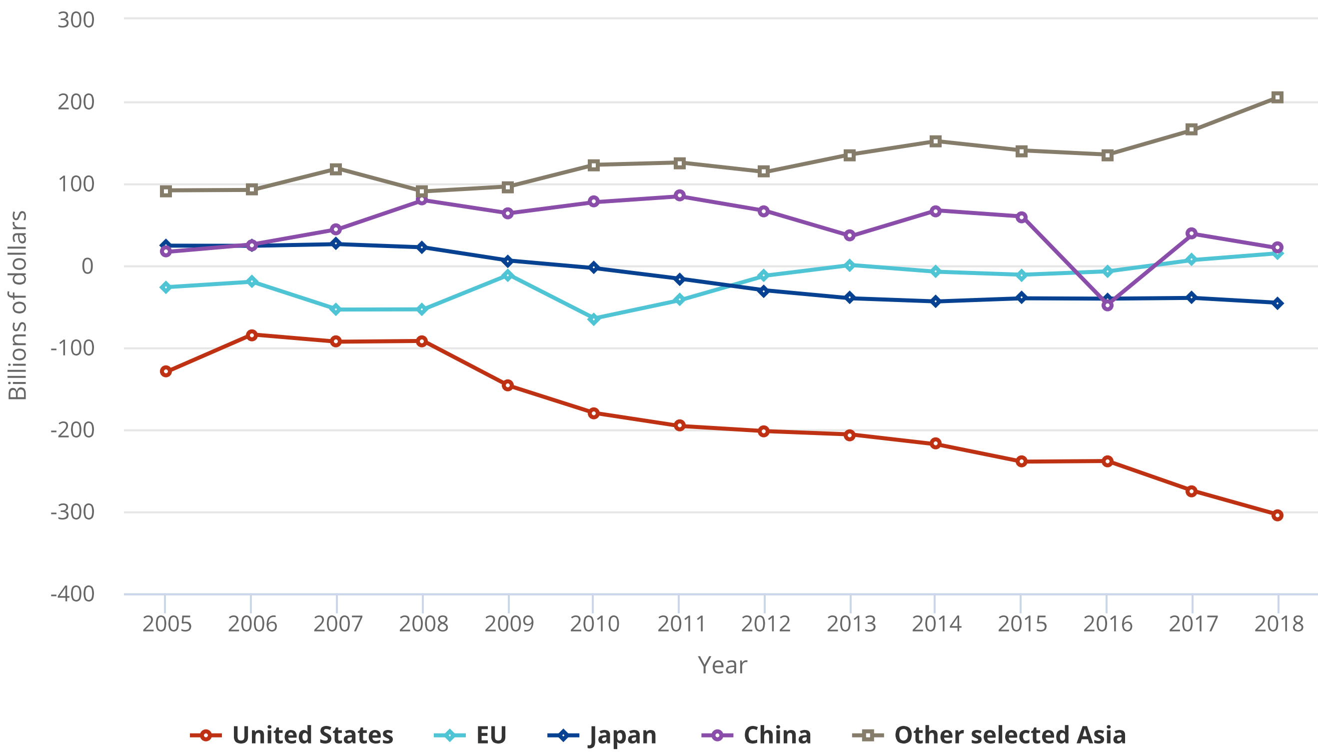
Source(s):

Oxford Economics, special tabulations (2019) of Global Trade Databank.

Science and Engineering Indicators

FIGURE 6-13

Trade balance of high R&D intensive products, by selected region, country, or economy: 2005–18



EU = European Union.

Note(s):

High R&D intensive products include aircraft; pharmaceuticals; and computer, electronic, and optical products classified by the Organisation for Economic Co-operation and Development. China includes Hong Kong. China data excludes bilateral flows between mainland China and Hong Kong. Other selected Asia includes India, Indonesia, Malaysia, the Philippines, Singapore, South Korea, Taiwan, Thailand, and Vietnam. See Table S6-19.

Source(s):

Oxford Economics, special tabulations (2019) of Global Trade Databank.

Science and Engineering Indicators

Although the world's largest exporter of high R&D intensive goods (31%), the EU's exports reflect the substantial volume of intra-regional trade among EU member countries (**Figure 6-12** and Table S6-19). In contrast, exports data for China and the United States do not include trade within their borders, which is likely to be substantial. Although EU exports grew over the last decade, the EU's global share has fallen from 36% to 31% during this period (Table S6-19).

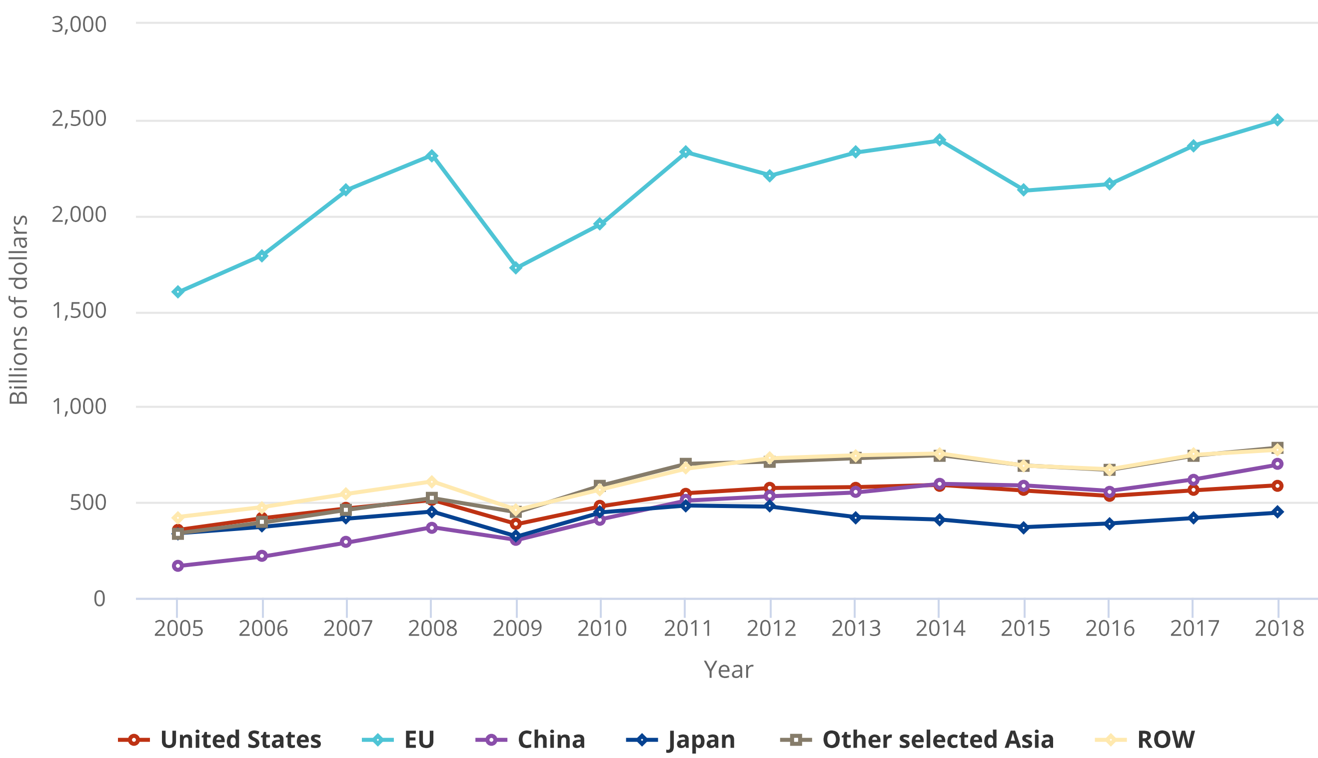
China is the second-largest global exporter (23%) (**Figure 6-12** and Table S6-19). China is the hub of "Factory Asia," which produces much of the world's electronic products that are part of high R&D intensive products. China imports and exports inputs and components from Asian economies, notably Japan, South Korea, Singapore, and Taiwan (Frederick and Lee 2017:24). China's exports grew significantly over the last decade with China's global share rising from 17% to 23%. China's trade surplus fell from $79 billion in 2008 to $21 billion in 2018, representing 3% of its exports (**Figure 6-13** and Table S6-19).

Trade in Medium-High R&D Intensive Products

Global exports of medium-high R&D intensive products—chemicals excluding pharmaceuticals; electrical equipment; other machinery and equipment; medical instruments; motor vehicles; railroad and other transport; and weapons—were $5.8 trillion in 2018 (**Figure 6-14** and Table S6-20). The U.S. trade position is very similar to its position in high R&D intensive products—the third largest exporter and far below the largest exporter, the EU (**Figure 6-14** and Table S6-20). The United States has a substantial trade deficit ($297 billion) that comprises 50% of its exports. The U.S. trade deficit has widened over the last decade (**Figure 6-15** and Table S6-20).

FIGURE 6-14

Exports of medium-high R&D intensive products, by selected region, country, or economy: 2005–18



EU = European Union; ROW = rest of world.

Note(s):

Medium-high R&D intensive products include weapons and ammunition; motor vehicles; medical and dental instruments; machinery and equipment; chemicals and chemical products; electrical equipment; and railroad, military vehicles, and transport classified by the Organisation for Economic Co-operation and Development. China includes Hong Kong. China data excludes bilateral flows between mainland China and Hong Kong. Other selected Asia includes India, Indonesia, Malaysia, the Philippines, Singapore, South Korea, Taiwan, Thailand, and Vietnam. See Table S6-20.

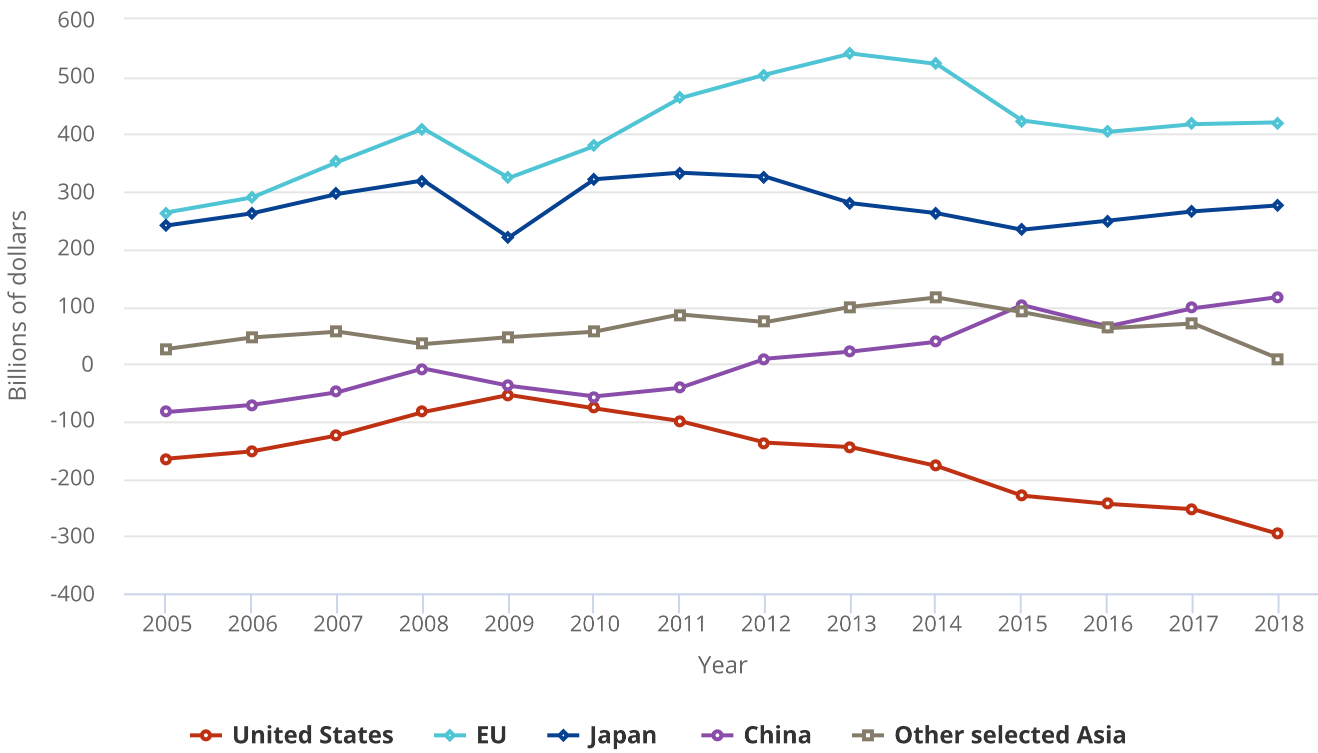
Source(s):

Oxford Economics, special tabulations (2019) of Global Trade Databank.

Science and Engineering Indicators

FIGURE 6-15

Trade balance of medium-high R&D intensive products, by selected region, country, or economy: 2005–18



EU = European Union.

Note(s):

Medium-high R&D intensive products include weapons and ammunition; motor vehicles; medical and dental instruments; machinery and equipment; chemicals and chemical products; electrical equipment; and railroad, military vehicles, and transport classified by the Organisation for Economic Co-operation and Development. China includes Hong Kong. China data excludes bilateral flows between mainland China and Hong Kong. Other selected Asia includes India, Indonesia, Malaysia, the Philippines, Singapore, South Korea, Taiwan, Thailand, and Vietnam. See Table S6-20.

Source(s):

Oxford Economics, special tabulations (2019) of Global Trade Databank.

Science and Engineering Indicators

Similar to high R&D intensive products, the EU is the world's largest exporter of medium-high R&D intensive products (**Figure 6-14** and Table S6-20) and its exports are bolstered by the substantial value of intra-EU trade. The EU has had a substantial trade surplus ($400–$500 billion) over much of the last decade accounting for 18%–23% of its total exports (**Figure 6-15** and Table S6-20). China is the second-largest global exporter, slightly ahead of the United States (**Figure 6-14** and Table S6-20). China's exports have grown rapidly over the last decade coinciding with China assembling and manufacturing many goods in medium-high R&D intensive industries including electrical equipment, other machinery and equipment, and motor vehicles. China has had a modest surplus since 2012 (**Figure 6-15** and Table S6-20). Japan is the fourth largest exporter and has a substantial trade surplus (**Figure 6-14**, **Figure 6-15**, and Table S6-20). Japan's exports have remained roughly flat since 2011.

SIDEBAR

Trade in Value Added of the Computer, Electronic, and Optical Products Industry

Goods and services, including R&D intensive products, are increasingly produced in global supply chains with inputs from various countries around the world. Value-added trade data trace the value contributed by each industry and country in the production chain and allocate it to the corresponding industries and countries. As such, value-added trade data measure net trade flows across countries. In contrast, conventional trade data measure the gross flows of goods and services as they cross borders. As such, they do not measure the country-specific value added or contribution to traded products composed of intermediate goods that have crossed borders multiple times.

Figure 6-E shows a simple example of trade associated with a good produced in a global value chain. Country A manufactures an intermediate input valued at $20 that is exported to Country B for further processing. Country A's exports to Country B are the same on a value-added and gross flow basis ($20). Country B manufactures an intermediate input and assembles the finished good. Country B adds value of $20, consisting of the value of its intermediate input ($10), and the value of final assembly ($10). Country B exports the finished good to Country C. Country B's gross exports are $40, consisting of Country A's intermediate input ($20) and the value added contributed by Country B ($20). Country B's value-added exports ($20) are lower than on a gross flow basis because the value of Country A's intermediate input is not credited to Country B's exports. Total exports on a value-added basis ($40) are lower than gross exports ($60) because gross exports count Country A's intermediate input twice: (1) Country A's exports to Country B and (2) Country B's exports. Total value-added exports count Country A's intermediate input once as part of Country A's export to Country B.

FIGURE 6-E

Example of trade in global value chain

(Dollars)

	Country A	Intermediate export	Country B	Final export	Country C
Measurement of export	Produces intermediate input ($20)	→	Produces intermediate input ($10) Performs final assembly ($10)	→	Imports and consumes final good
Value-added exports		$20		$40	
Gross exports		$20		$60	

Science and Engineering Indicators

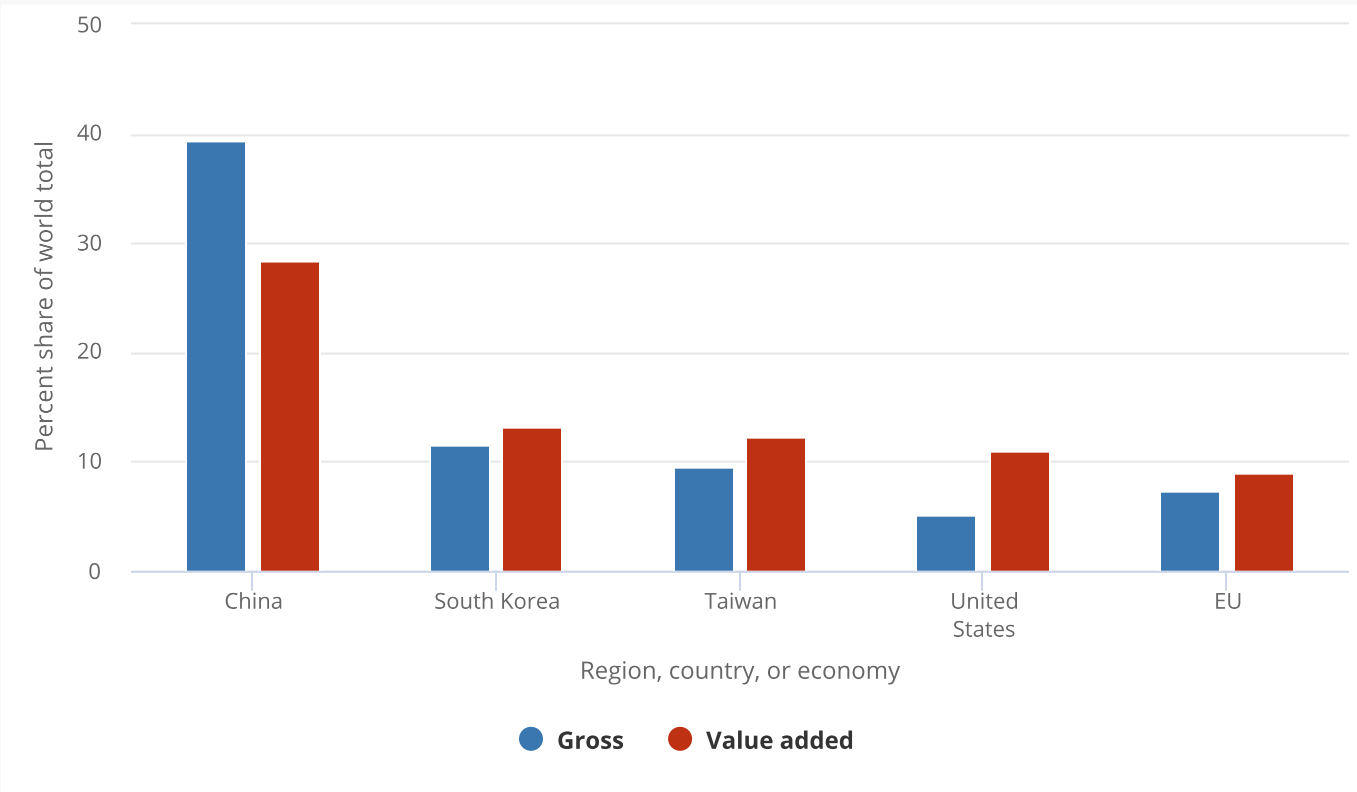
The Trade in Value Added joint initiative of the Organisation for Economic Co-operation and Development (OECD) and the World Trade Organization (WTO) has estimates of trade in value added that measure the contribution that each country provides in goods produced in global value chains.* The OECD/WTO database has value-added and conventional data on the computer, electronic, and optical products category, which is a major component of high

R&D intensive products. The OECD/WTO value-added data suggest that the United States has a comparatively stronger trade position than conventional data show while China has a somewhat weaker position. Measuring U.S. exports on a value-added basis credited the United States for the exports of inputs and components to China and other countries, which were credited to the location of final assembly, mainly China, on a conventional basis.

On a conventional basis, the United States was the fifth-largest exporter (5% global share), far below first-ranked China in 2015 (**Figure 6-F**). On a value-added basis, the U.S. export share is higher (11%), making it roughly the same level as Taiwan and the EU (**Figure 6-F**). In addition, the gap between the export share of China and the United States, while still substantial, is smaller on a value-added basis. The larger export share of the United States on a value-added versus conventional basis is explained by its far lower share of foreign content compared to other major exporters (**Figure 6-G**).

FIGURE 6-F

Exports of computer, electronic, and optical equipment, by selected region, country, or economy: 2015



EU = European Union.

Note(s):

Exports measured on a gross basis include value of domestic content and intermediate inputs supplied by other countries. Exports measured on value-added basis include value of domestic content and exclude value of intermediate inputs supplied by other countries. U.S. exports do not include exports to Canada and Mexico. The EU includes 28 current member countries. EU exports do not include exports among individual EU member countries. China includes Hong Kong. China's exports do not include exports between mainland China and Hong Kong.

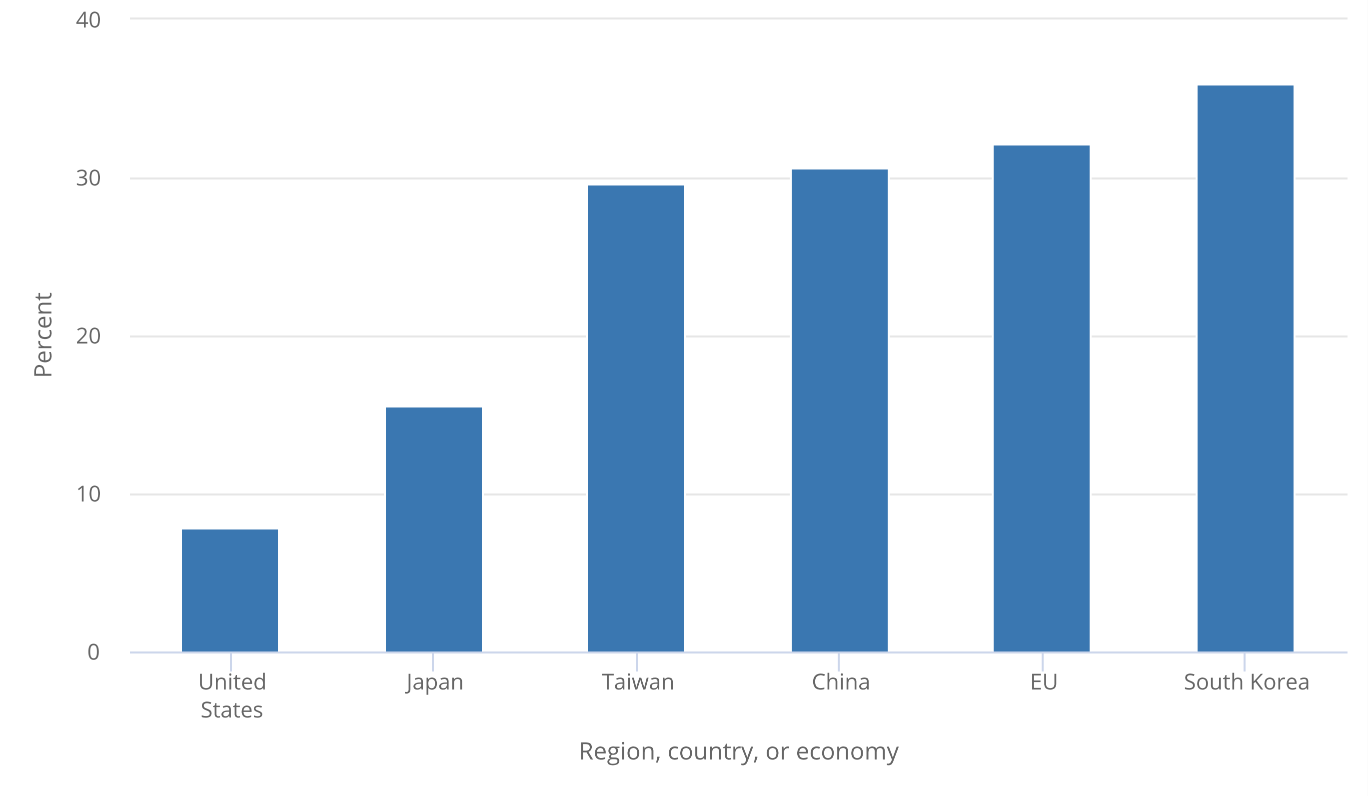
Source(s):

Organisation for Economic Co-operation and Development, Trade in Value Added Database.

Science and Engineering Indicators

FIGURE 6-G

Foreign content share of gross exports of the computer, electronic, and optical equipment industry, by selected region, country, or economy: 2015



EU = European Union.

Note(s):
Foreign content is the value of imported intermediate goods and services from other countries that are embodied in gross exports. U.S. exports do not include exports to Canada and Mexico. The EU includes 28 current member countries. EU exports do not include exports among individual EU member countries. China includes Hong Kong. China's exports do not include exports between mainland China and Hong Kong.

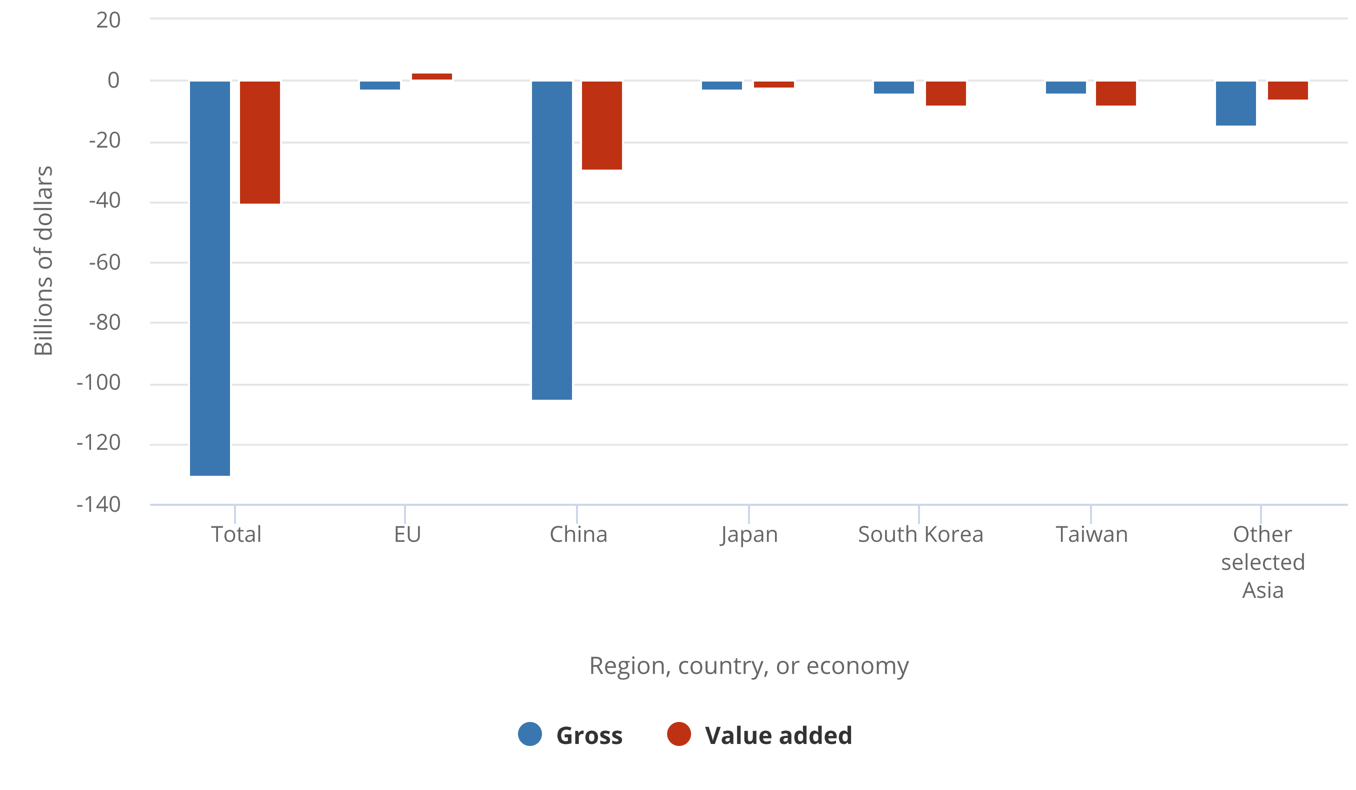
Source(s):
Organisation for Economic Co-operation and Development, Trade in Value Added Database.

Science and Engineering Indicators

The higher U.S. global export share on a value-added basis coincides with a much smaller U.S. trade deficit compared to a conventional basis, largely due to a much smaller deficit with China (**Figure 6-H**). Value-added measurement of U.S. trade with China results in comparatively lower imports from China by crediting the foreign content of China’s imports to the countries that supplied inputs and components to China.

FIGURE 6-H

U.S. trade balance in the computer, electronic, and optical equipment industry by selected region, country, or economy: 2015



EU = European Union.

Note(s):

Exports and imports on a gross basis include value of domestic content and intermediate inputs supplied by other countries. Exports and imports on a value-added basis consist of value of domestic content and exclude value of intermediate inputs supplied by other countries. U.S. trade balance excludes trade with Canada and Mexico. The EU includes current 28 member countries. China includes Hong Kong. Other selected Asia includes India, Indonesia, Malaysia, the Philippines, Singapore, Thailand, and Vietnam.

Source(s):

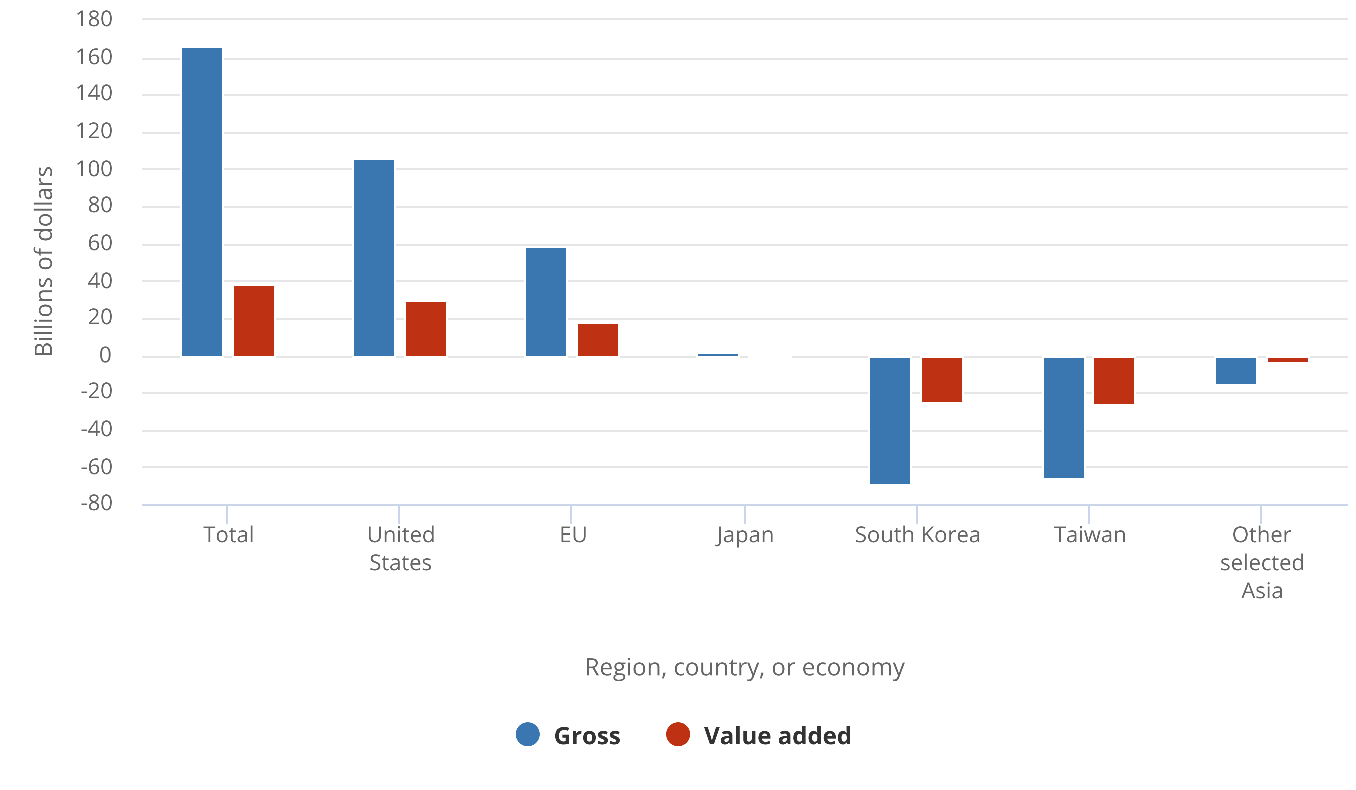
Organisation for Economic Co-operation and Development, Trade in Value Added Database.

Science and Engineering Indicators

According to the OECD/WTO value-added data, China is the world's largest exporter (39% global share) on a conventional basis, with a wide lead over other major exporters (**Figure 6-F**). Although it continues to be the largest global exporter on a value-added basis, China's global share is lower (28%), and the gap between China and other major exporters is narrower. The large decline of China's global share moving from a conventional to a value-added basis is due to the high share of foreign content in China's exports. In addition, China's trade surplus is much lower on a value-added basis ($38 billion) than on a conventional basis ($166 billion) due to a far smaller bilateral surplus with the United States (**Figure 6-I**).

FIGURE 6-I

China's trade balance in the computer, electronic, and optical equipment, by selected region, country, or economy: 2015



EU = European Union.

Note(s):

Exports and imports measured on a gross basis include value of domestic content and intermediate inputs supplied by other countries. Exports and imports measured on value-added basis include value of domestic content and exclude value of intermediate inputs supplied by other countries. U.S. trade excludes exports and imports with Canada and Mexico. The EU includes current 28 member countries. China includes Hong Kong. Other selected Asia includes India, Indonesia, Malaysia, the Philippines, Singapore, Thailand, and Vietnam.

Source(s):

Organisation for Economic Co-operation and Development Trade in Value Added Database.

Science and Engineering Indicators

* Data on the OECD/WTO trade in value-added indicators and additional information are available at **https://www.oecd.org/industry/ind/measuringtradeinvalue-addedanoecd-wtojointinitiative.htm**.

Artificial Intelligence Technology

Artificial intelligence is defined by the Oxford English dictionary as “the theory and development of computer systems able to perform tasks normally requiring human intelligence.” A core objective of AI research and technologies is to automate or replicate human learning and cognition (Executive Office of the President 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 the nature of work (Cockburn 2018; WIPO 2019). These rapid changes are widely expected to have large and long-term economic and technological effects on society, including sectors and occupations not historically impacted by technology.

AI is expected to automate or augment a broad range of work tasks compared to the narrower range of routine, highly structured, and repetitive tasks that were automated by ICT (Brynjolfsson and Mitchell 2017). For example, AI has the potential to impact the nature of work and employment in two industries—medicine and finance—that have not had significant disruptions in employment from past technologies (Frank et al. 2019). AI is expected to have broad impacts like other general purpose technologies (GPTs), such as the steam engine, electrification, and IT. GPTs are a special category of technologies that are widely used and capable of ongoing technical improvement and of enabling innovation in application sectors (Bresnahan 2010). AI's impacts on the economy and society are likely to take at least several decades to become apparent based on the experience of past GPTs (Brynjolfsson, Rock, and Syverson 2018).

Experts predict that AI will increase the effectiveness and the frequency of cyberattacks on computer networks, thefts of personal data, and spread of computer viruses (Yampolskiy 2017). The federal government and corporations are supporting a wide range of research on enhancing cybersecurity, including developing AI to detect and defend against attacks (Dietterich and Horvitz 2015). Furthermore, there is a concern that AI may increase inequality across individuals, groups, and countries through the “digital divide” (Williams 2018:103–4). This digital divide refers to gaps in access to information and communication technology (OECD n.d.). In addition to inequalities in access to digital technologies, two additional potential impacts are inequalities in digital skills and technology use as well as outcomes, both benefits and harms (Lutz 2019:144).

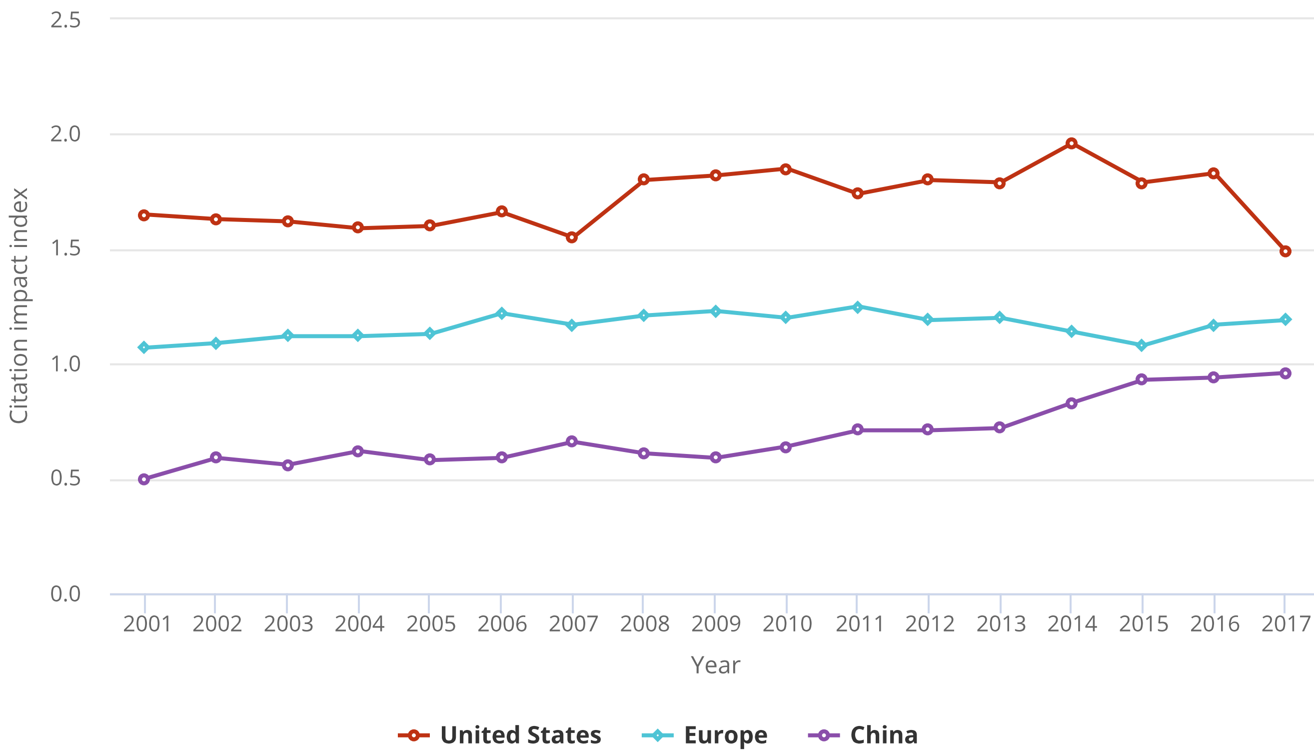
AI research areas and technologies include machine learning, autonomous robotics and vehicles, computable statistics, computer vision, language processing, virtual agents, and neural networks (Furman and Seamans 2018). The data presented in this section cover a variety of indicators related to AI, including publication, job opening, business spending and capabilities, and venture capital funding. The **Technical Appendix** to this report describes the data sources.

AI Research: China and the United States

The production and citation of peer-reviewed publications is an indicator of the creation, dissemination, and impact of S&E knowledge about AI (for a comprehensive discussion of S&E publication data, see *Indicators 2020* report “Publications Output: U.S. Trends and International Comparisons”). Based on an analysis by Elsevier (2018), U.S. scientific publications in AI are more frequently cited than those from Europe and China, suggesting that U.S. research has relatively more impact (**Figure 6-16**). Elsevier (2018) also suggests that the impact of China’s AI research has been rising in the last several years (**Figure 6-16**).

FIGURE 6-16

Citation impact of AI scientific papers by selected region or country: 2001–17



AI = artificial intelligence.

Note(s):

The citation impact shows the degree of citing AI publications in a region or country relative to the world. An impact of 1.0 indicates that AI scientific publications are cited at the same frequency as all other regions. An impact of greater (less) than 1.00 indicates that the publications of a region/country are cited more (less) that would be expected.

Source(s):

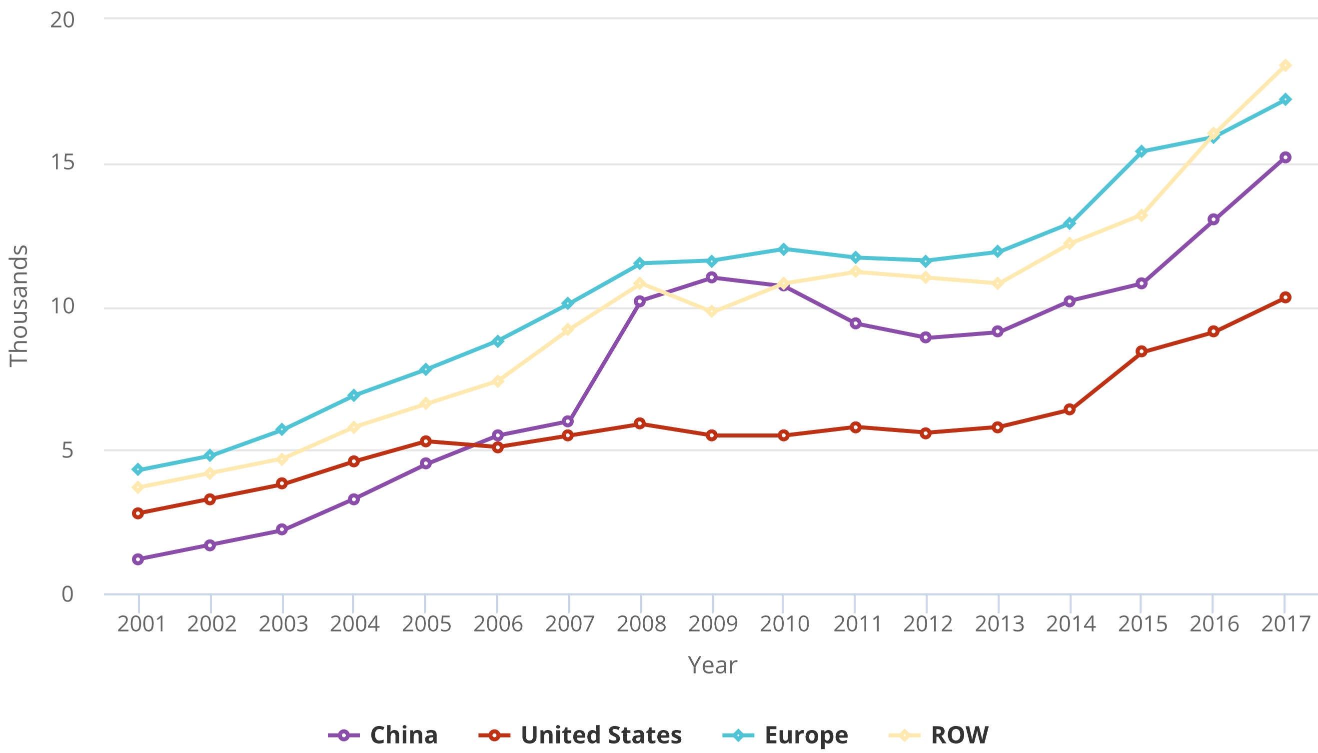
The 2018 AI Index Report. 2018. Artificial Intelligence Index.

Science and Engineering Indicators

By number of publications, China's AI output has grown far more rapidly than the United States and Europe over the last decade, resulting in China becoming the leading country producing AI scientific articles (25% share) followed by the United States (17%) (**Figure 6-17**). China's AI scientific publications have had a significant degree of international collaboration. For example, one study noted that more than half of China's AI papers were authored jointly with other countries (Allen 2019:11). In addition, the expansion in the volume of scientific articles outside of Europe, China, and the United States suggests that research capability is strengthening in the rest of the world.

FIGURE 6-17

AI scientific publications by region, country, or economy: 2001–17



AI = artificial intelligence; ROW = rest of world.

Note(s):
The data source for AI scientific publications is Scopus.

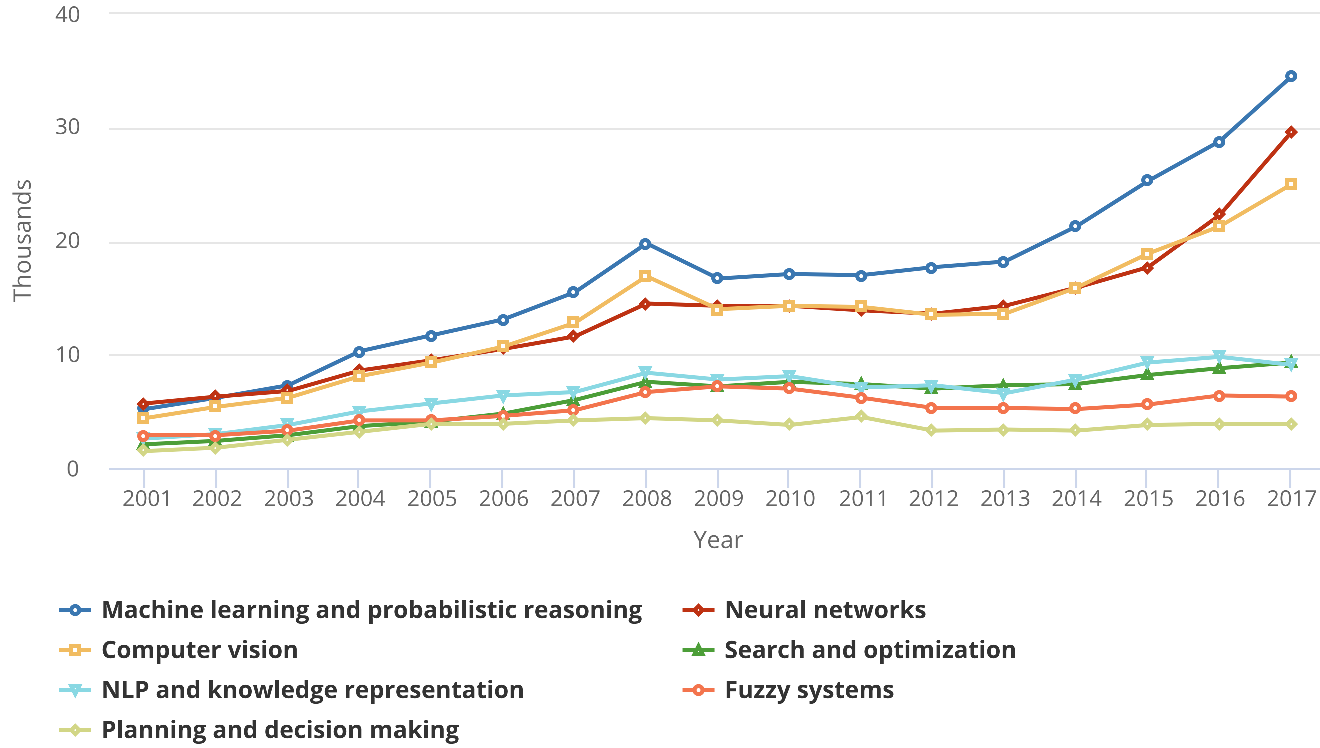
Source(s):
The 2018 AI Index Report. 2018. Artificial Intelligence Index.

Science and Engineering Indicators

The number of publications grew most rapidly in three AI topic areas: machine learning and probabilistic reasoning, neural networks, and computer vision (**Figure 6-18**). Machine learning is a branch of computational statistics that develops algorithms to execute or solve specialized tasks and problems. Neural networks are an AI technology that closely mimic the human brain's underlying architecture to provide capability in reasoning and problem solving. Examples that illustrate the rapid advancement of this form of AI technology include (1) the improved accuracy of AI translating news between languages, (2) the declining training time for AI to recognize an image from an image database, and (3) the improving score for AI answering grade school-level multiple-choice science questions.

FIGURE 6-18

AI scientific publications, by area or technology: 2001–17



AI = artificial intelligence; NLP = natural language processing.

Note(s):
The data source for AI scientific publications is Scopus.

Source(s):
The 2018 AI Index Report. 2018. Artificial Intelligence Index.

Science and Engineering Indicators

SIDEBAR

Commercialization of Artificial Intelligence

The commercialization of artificial intelligence (AI) is occurring in four separate areas: Internet, business, perception, and autonomous (Lee 2018). Internet AI is largely about using AI algorithms as recommendation engines—AI systems that recommend content based on our personal preferences (Lee 2018:107). For example, Netflix recommends movies and TV shows to watch based on a viewer's history, and Facebook targets advertisements to users based on their activity, including their posts news and interaction with other users.

The second area, business AI, mines the databases of companies and organizations to develop algorithms to match or outperform humans (Lee 2018:110–11). For example, the financial industry has developed algorithms to approve mortgages based on the applicant's credit record, income, and other characteristics. Researchers in the United States have demonstrated algorithms to diagnose specific illnesses based on images that are on par with doctors (Lee 2018:113). These two areas have been widely implemented and are beginning to have substantial economic impact.

The third area, perception AI, is digitizing the physical environment through the proliferation of sensors and smart devices. These devices turn the physical world into digital data that can be analyzed and optimized by AI algorithms.

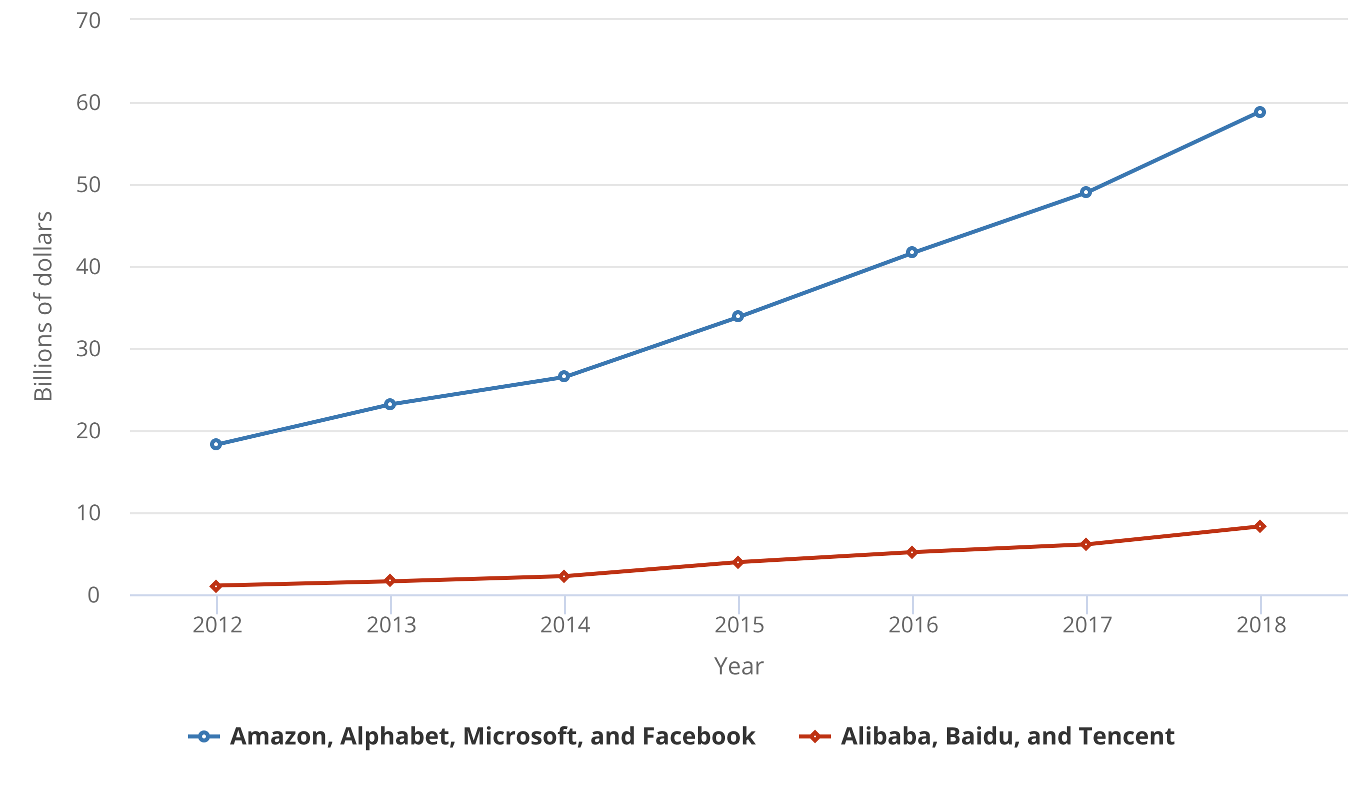
The fourth area, autonomous AI, includes autonomous vehicles and drones, intelligent robots, and other devices and hardware that will replace or supplement human labor, such as truck drivers. Technologies in this area generally remain under development or have not been widely commercialized compared to the other three areas (Lee 2018:106). For example, Google and other companies are testing autonomous cars to further refine and develop the technology.

The commercialization of AI technology in China and the United States has been occurring predominantly in large high-technology corporations and startups. According to Lee (2018:83), the “Seven Giants of the AI Age,” four companies based in the United States—Alphabet (the parent company of Google), Facebook, Amazon, and Microsoft—and three companies in China—Baidu, Alibaba, and Tencent—have invested heavily in AI R&D and acquisition of talent. For context, data on total R&D of these seven corporations suggest that their R&D spending in AI has been increasing substantially. R&D spending by the four U.S. companies more than tripled from $18 billion in 2012 to $59 billion in 2018 (**Figure 6-J**). In 2018, Amazon and Alphabet were the first and second ranked companies in corporate R&D spending in the world (Jaruzelski, Chwalik, and Goehle 2018). R&D spending by the three Chinese corporations also grew rapidly, an eight-fold increase from a collective total of $1 billion to $8 billion. In 2018, Alibaba, Tencent, and Baidu were the first, second, and fourth largest spenders on R&D among Chinese corporations. The strategy of these large Chinese and U.S. corporations has been to construct privately controlled computing networks that distribute AI technology with wide applications across the economy, similar to utilities distributing energy across power grids (Lee 2018:83). For example, Amazon is selling AI services, including natural language processing, speech synthesis, image analysis, and video recognition, with the goal of serving large- and small-time developers that want AI without upfront costs (CB Insights 2018:27). Alibaba is working with the city of Hangzhou to optimize traffic flows and alert emergency services to traffic accidents using advanced object recognition and predictive transit algorithms (Lee 2018:94).

In contrast to the general AI grid approach of large corporations, the AI startups are building highly specific “battery-powered” AI products that are stand-alone applications. The battery-powered AI products are for specific tasks, including medical diagnosis, mortgage lending, and autonomous drones (Lee 2018:95).

FIGURE 6-J

R&D spending of seven AI-focused corporations: 2012–18



AI = artificial intelligence.

Source(s):
PwC, The 2018 Global Innovation 1000 study.

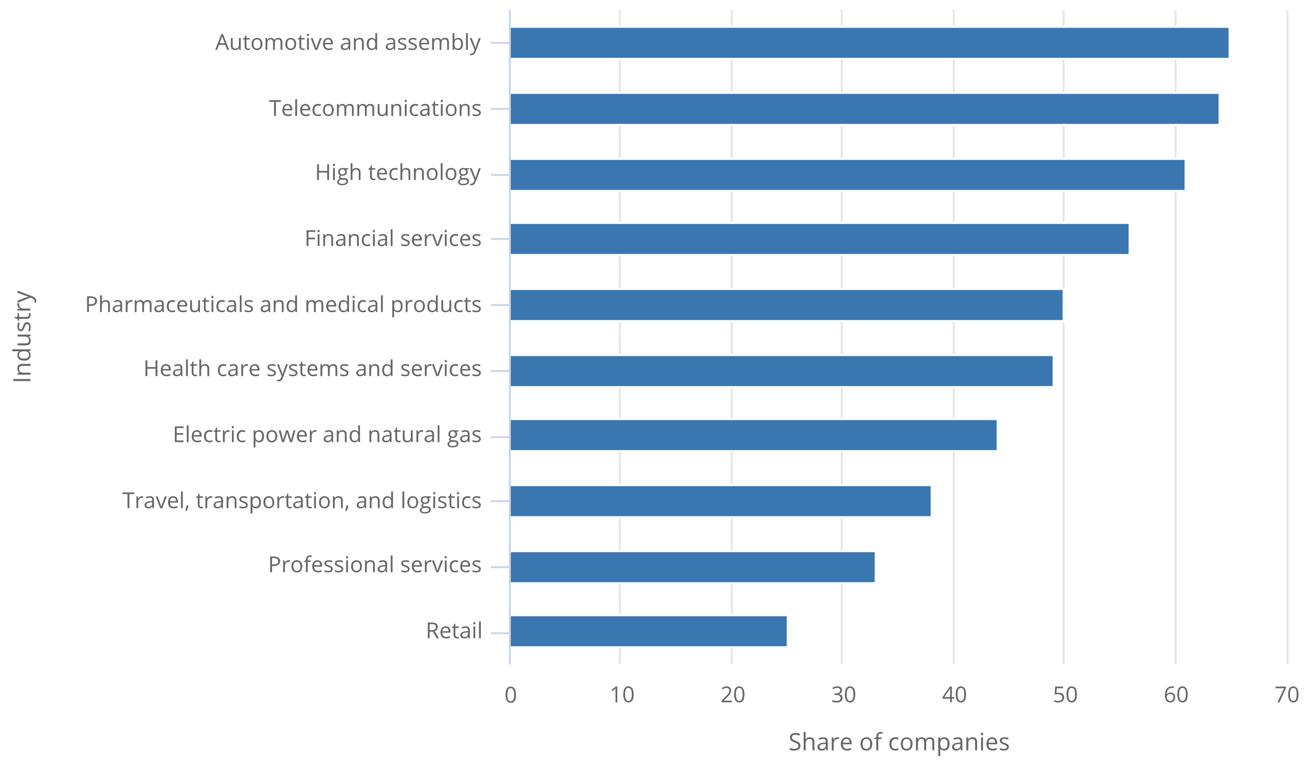
Science and Engineering Indicators

AI Adoption

While comprehensive business sector data are limited, a recent McKinsey and Company survey of businesses internationally finds AI has been adopted to some degree by a wide range of industries as measured by AI embedded in at least one business unit of the company (**Figure 6-19**). Industries with the highest adoption rates (greater than 55%) were automotive and assembly, telecommunications, high technology, and financial services. Many companies within these industries produce or use AI technologies in manufacturing their products or delivering their services. Firms reporting in the McKinsey survey indicate global AI adoption, including North America, Europe, Asia-Pacific, Middle East, India, and other developing countries (**Table 6-3**). The adoption rates of developing countries and regions rival or exceed those of developed regions, including North America. The most widely adopted AI technologies are conversational interfaces, robotic process automation, and computer vision. Technologies that have the lowest adoption rates include natural language text understanding, natural language speech understanding, and autonomous vehicles. The sidebar **Commercialization of Artificial Intelligence** has more information on the adoption of AI in the marketplace.

FIGURE 6-19

Adoption of AI capabilities, by industry: 2018



AI = artificial intelligence.

Note(s):
Share is ratio of companies with AI embedded in at least business unit to all companies in each industry.

Source(s):
The 2018 AI Index Report. 2018. Artificial Intelligence Index.

Science and Engineering Indicators

TABLE 6-3

Company adoption of AI technologies, by country, region, or economy: 2018

(Share of responding companies)

Technology	North America	Latin America	Europe	Asia-Pacific	India	Middle East / North Africa	Developing markets
Conversational interfaces	20.0	29.0	22.0	23.0	22.0	24.0	26.0
Robotic process automation	23.0	19.0	27.0	22.0	30.0	21.0	23.0
Computer vision	23.0	13.0	21.0	15.0	25.0	16.0	19.0
Machine learning	20.0	12.0	20.0	12.0	24.0	8.0	23.0
NL generation	16.0	9.0	17.0	17.0	16.0	21.0	17.0
Physical robotics	17.0	11.0	16.0	10.0	19.0	5.0	20.0
NL text understanding	16.0	7.0	12.0	7.0	15.0	3.0	15.0
NL speech understanding	11.0	7.0	10.0	5.0	16.0	5.0	14.0
Autonomous vehicles	5.0	2.0	7.0	5.0	9.0	8.0	12.0

AI = artificial intelligence; NL = natural language.

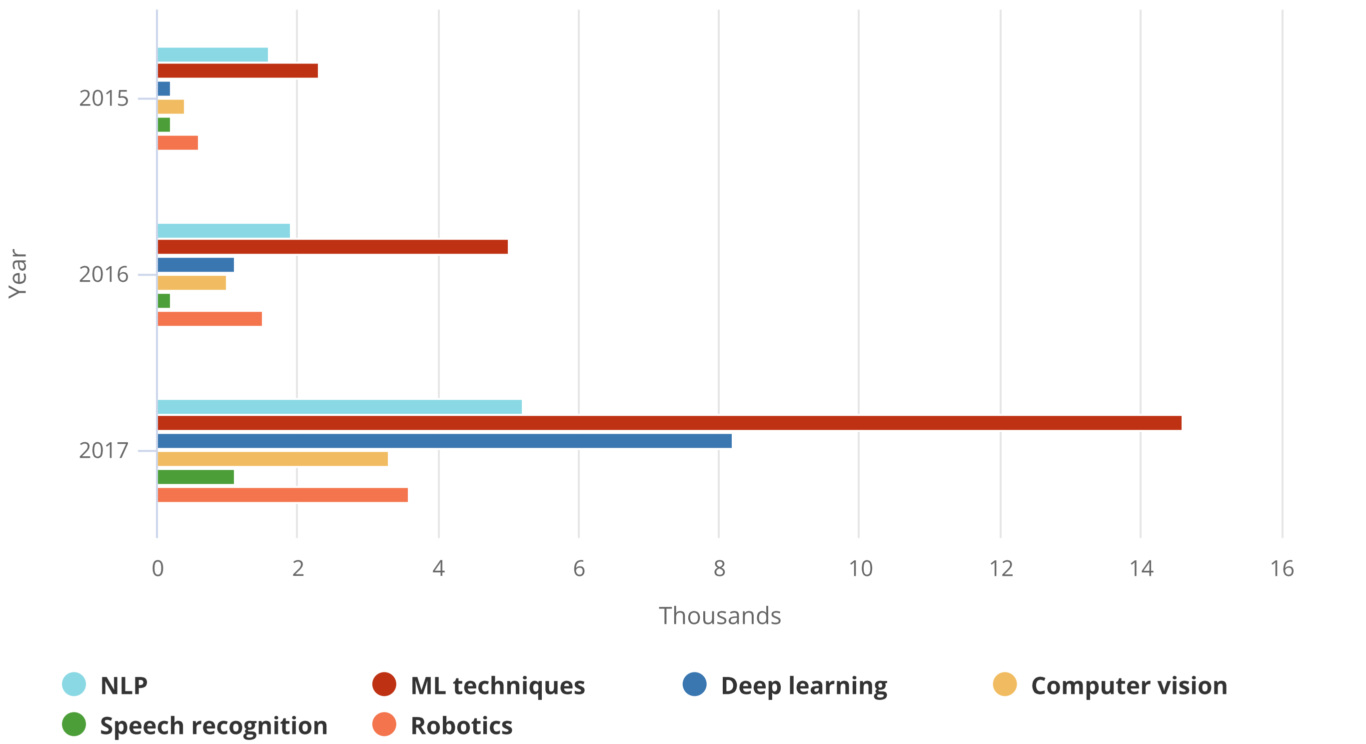
Source(s):
The 2018 AI Index Report. 2018. Artificial Intelligence Index.

Science and Engineering Indicators

Résumé databases provide another indicator of the skills that are most searched for in relation to AI. Searches on Monster.com show that for the United States the number of jobs requiring AI skills is small but rapidly growing (**Figure 6-20**). Job openings requiring AI skills on Monster.com jumped from 5,000 in 2015 to 36,000 in 2017, led by machine learning techniques, deep learning, and natural language processing.

FIGURE 6-20

Job openings on Monster.com, by AI skills required: 2015–17



AI = artificial intelligence; ML = machine learning; NLP = natural language processing.

Source(s):
The 2018 AI Index Report. 2018. Artificial Intelligence Index.

Science and Engineering Indicators

AI Initiatives in the United States and China

In 2016, the U.S. government released its first initiative on AI. The stated goals include public funding of AI R&D, development of a skilled AI workforce, regulation to encourage innovation while protecting the public, and support for workers that are negatively affected by AI (Executive Office of the President 2016:3–4). In 2019, the United States released the "American AI Initiative" proposing sustained investment in AI R&D and increased collaboration among government, industry, academia, nonprofits, and other countries. The plan also includes as stated goals policies to increase the pipeline of AI talent; enhance access to U.S. government data, models, and computing resources; and protect U.S. AI research and technology against strategic competitors and foreign adversaries (Metz 2019).

In 2017, China announced the Next Generation Artificial Intelligence Plan with the stated goal of becoming the "world's premier global AI innovation center" with its AI industry projected to be valued at about $150 billion in 2030 (Kania 2017). Other stated goals in the plan include the development of an AI talent pipeline, large-scale government procurement of AI technology, promotion of collaboration between the private sector, universities, and government and investments in mitigation of AI's potential risks and societal disruption, including a large-scale replacement of jobs by AI (Allen and Kania 2017; Lee 2018:84). China's plan reflects a collaborative initiative where China's central, regional, and local governments all play roles (Lee 2018:98–99).

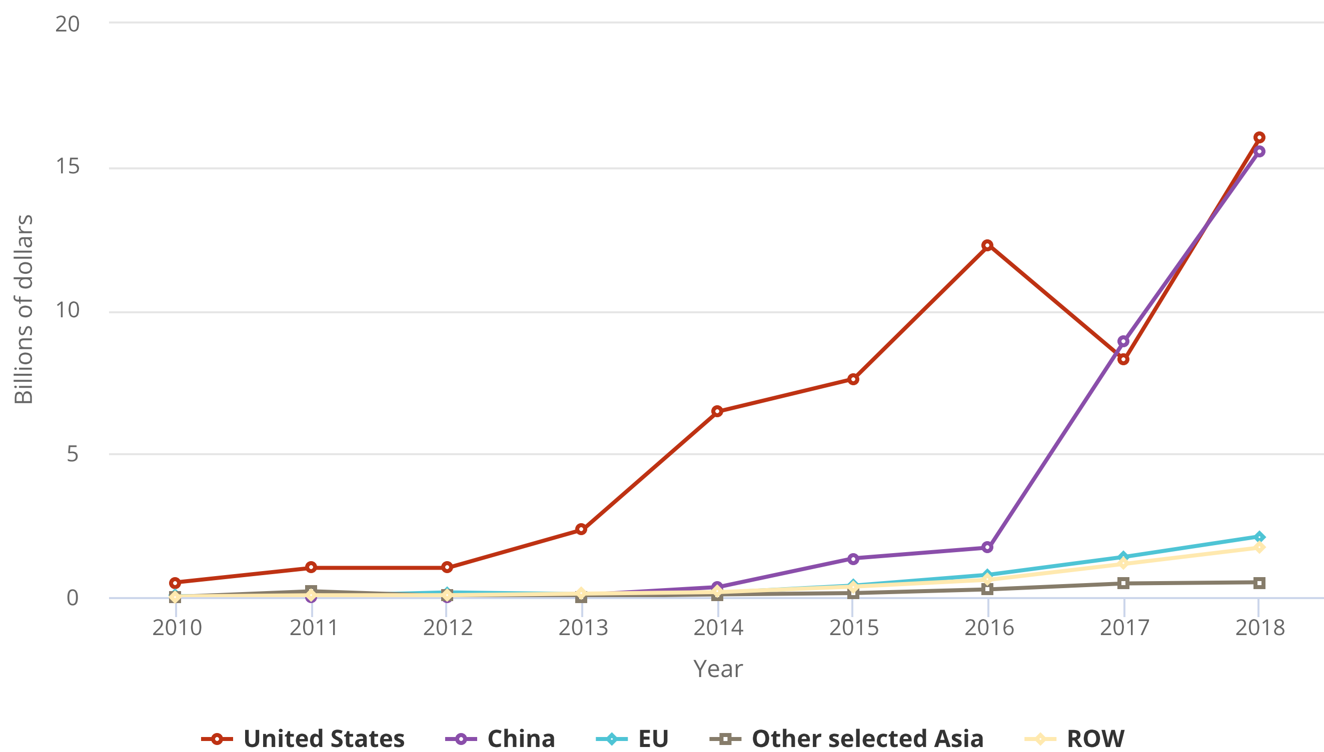
Venture Capital in AI

AI startups depend heavily on venture capital funding. This section presents data from PitchBook, a company that collects venture capital data by country, industry, and technology area. These data are shown more extensively across technology areas in the *Indicators 2020* report "Invention, Knowledge Transfer, and Innovation." For context, the global total of venture capital investment was $244 billion in 2018, with $113 billion invested in the United States and $76 billion in China.

AI-related venture capital funding has grown rapidly from less than $1 billion in 2010 to $36 billion in 2018 with the majority of the funds being invested in the United States followed by China (**Figure 6-21**). Investment in China soared after 2016, resulting in its 28% global share in 2018. The U.S. global share dropped from an average of 83% in 2010–16 to 54% in 2017–18. The number of AI startups in the United States receiving venture capital investment more than doubled from almost 600 in 2014 to more than 1,500 in 2018 (**Table 6-4**). The number of startups in China, although smaller than that in the United States, also grew rapidly.

FIGURE 6-21

Venture capital investment in AI, by selected region, country, or economy: 2010–18



AI = artificial intelligence; EU = European Union; ROW = rest of world.

Note(s):

China includes Hong Kong. Other selected Asia includes India, Indonesia, Japan, Singapore, and South Korea.

Source(s):
PitchBook, venture capital and private equity database.

Science and Engineering Indicators

TABLE 6-4

AI companies and deals financed by venture capital in China and the United States: 2014–18

(Number)

Companies or deals	2014	2015	2016	2017	2018
Companies					
China	53	123	184	259	284
United States	575	726	1,010	1,387	1,544
Deals					
China	68	148	210	306	335
United States	683	826	1,238	1,753	1,955

AI = artificial intelligence.

Source(s):
PitchBook, venture capital and private equity database, accessed 24 September 2019.

Science and Engineering Indicators

Conclusion

The United States remains the largest producer in high R&D intensive industries. China has been making rapid progress and is now tied with the EU as the second-largest producer. China is the largest global producer in medium-high R&D intensive industries, followed by the EU, with the United States a distant third. Many KTI industries are either developing or utilizing AI technologies, including the software publishing, IT services, and computer, electronic and optical products industries. Furthermore, AI is 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; however, business adoption of AI technologies is occurring across the world, including North America, Europe, Asia-Pacific, Middle East, and India and other developing countries.

Glossary

Definitions

Company or firm: A business entity that is either in a single location with no subsidiaries or branches or the topmost parent of a group of subsidiaries or branches.

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

Foreign direct investment: Financial investment by which a person or an entity acquires a lasting interest in and a degree of influence over the management of a business enterprise in a foreign country.

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

High R&D intensive industries: Industries classified by the OECD that spend a high proportion of their revenue on R&D, consisting of aircraft; computer, electronic, and optical products; pharmaceuticals; scientific R&D services; and software.

Intra-EU exports: Exports from one EU country to another.

IT and information services (IT services): This industry is the composite of 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 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 (output).

Manufacture of air- and spacecraft and related machinery (aircraft): 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 (ICBM); overhaul and conversion of aircraft or aircraft engines; and aircraft seats.

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

Manufacture of chemicals and chemical products (chemicals excluding pharmaceuticals): This industry includes the transformation of organic and inorganic raw materials by a chemical process and the formation of products.

Manufacture of computer, electronic and optical products (computer, electronic and optical products): 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 the manufacture of magnetic and optical media.

Manufacture of electrical equipment (electrical equipment): 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.

Manufacture of machinery and equipment not elsewhere classified (nec) (machinery and equipment): 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 hand-held 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.

Manufacture of medical and dental instruments and supplies (medical instruments): 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.

Manufacture of motor vehicles, trailers, and semi-trailers (motor vehicles): 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.

Manufacture of railway locomotives and rolling stock, military fighting vehicles, and transport equipment nec (railroad and other transportation): This industry is the composite of 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.

Manufacture of weapons and ammunition (weapons): This industry includes the manufacture of heavy weapons (artillery, mobile guns, rocket launchers, torpedo tubes, heavy machine guns); small arms (revolvers, shotguns, light machine guns); air and gas guns and pistols; war ammunition; hunting, sporting, and protective firearms and ammunition; and explosive devices such as bombs, mines and torpedoes.

Medium-high technology manufacturing industries: Industries classified by the OECD that spend a relatively high proportion of their revenue on R&D, consisting of chemicals excluding pharmaceuticals; electrical equipment; information technology (IT) services; machinery and equipment; medical instruments; motor vehicles; railroad and other transportation; and weapons.

Publishing activities (publishing): This industry includes the publishing of books, brochures, leaflets, dictionaries, encyclopedias, atlases, maps and charts; publishing of newspapers, journals, and periodicals; directory and mailing list and other publishing, as well as software publishing. Publishing includes the acquisition of copyrights to content (information products) and making this content available to the public by engaging in (or arranging for) the reproduction and distribution of this content in various forms. All the feasible forms of publishing (in print, electronic or audio form, on the Internet, as multimedia products such as CD-ROM reference books, etc.), except publishing of motion pictures, are included in this industry.

Scientific research and development (scientific R&D services): This industry includes the activities of three types of research and development: (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 towards 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, to installing new processes, systems and services, and to improving substantially those already produced or installed.

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

Value chain: A chain of activities to produce goods and services that may extend across firms or countries. These activities include design, production, marketing and sales, logistics, and maintenance.

Venture capital: Venture capitalists manage the pooled investments of others (typically wealthy investors, investment banks, and other financial institutions) in a professionally managed fund. In return, venture capitalists receive ownership equity and almost always participate in managerial decisions.

Key to Acronyms and Abbreviations

AI: artificial intelligence

EU: European Union

GDP: gross domestic product

ICT: information and communication technologies

IT: information technology

KTI: knowledge- and technology-intensive

OECD: Organisation for Economic Co-operation and Development

R&D: research and development

S&E: science and engineering

WTO: World Trade Organization

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Notes

1 For more information on the OECD's methodology in identifying R&D intensive industries, see the **Technical Appendix** and Galindo-Rueda F, Verger F. 2016. *OECD Taxonomy of Economic Activities Based on R&D Intensity*. OECD Science, Technology and Industry Working Papers, 2016/04, OECD Publishing, Paris. **https://www.oecd-ilibrary.org/docserver/5jlv73sqqp8r-en.pdf?expires=1555622432&id=id&accname=guest&checksum=F080BDBDCDEC9AD8E8DDE43B567BD4B8**. Accessed 18 April 2019.

2 Foreign content share of the pharmaceuticals industry is not available.

3 For a discussion of the various factors that have contributed to the stagnation of Japan's economy, see Funabashi Y, Kushner B, editors. 2015. *Examining Japan's Lost Decades*. NY: Routledge.

Errata

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The original text stated that China became the largest producer in the computer, electronic, and optical products industry in 2013 instead of 2014. The text has been corrected consistent with data in Table S6-7. No other formats were impacted.

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Report Author

Derek Hill
Economist
Science & Engineering Indicators Program
National Center for Science and Engineering Statistics
dhill@nsf.gov

NCSES

National Center for Science and Engineering Statistics
Directorate for Social, Behavioral and Economic Sciences
National Science Foundation
2415 Eisenhower Avenue, Suite W14200
Alexandria, VA 22314
Tel: (703) 292-8780
FIRS: (800) 877-8339
TDD: (800) 281-8749
ncsesweb@nsf.gov