CHAPTER 8

Invention, Knowledge Transfer, and Innovation

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Highlights

Innovation Occurs in an Interconnected System with S&E as a Key Component

The S&E workforce and R&D activity increase the capital stock of knowledge—either through fundamental scientific advances or by extending basic knowledge for practical applications. This knowledge storehouse, in turn, serves as a key resource for those who invent and innovate. Intertwined economic and organizational processes link knowledge advances to invention, knowledge transfer, and innovation.

- The S&E-trained workforce conducts research to make discoveries and create new technologies.
- Businesses, universities, federal laboratories and research centers, and nonprofit institutions all contribute to discoveries.
- Production and trade in knowledge-intensive goods and services fuel the transfer of S&E into commercial applications.
- The theory and data available advance our understanding of the innovation system and its important dynamics. However, metrics to gauge performance and effectiveness are incomplete, particularly for outcomes and impacts.

Inventions and the Rate of Their Discovery Are Essential Features of a National Innovation System

An invention brings something new into being and has a practical bent—the production of a new product or process that is potentially useful, previously unknown, and nonobvious. Patent data, valuable for their technological and geographic detail, are indicators of invention, rather than innovation.

The number of patents from the U.S. Patent and Trademark Office (USPTO) granted to U.S. inventors continues to grow, although at a slower rate than was seen earlier in the decade. The most well-defined metrics on U.S. inventions are patent applications and awards and the invention disclosures reported by the technology transfer offices at academic institutions and at the nation's federal laboratories. Comprehensive patent data have become increasingly available and extensively analyzed in recent years. Invention disclosures are accessible in regular reports. Nonetheless, both these sets of data provide only a partial picture of U.S. invention.

- Foreign owners account for more than half of USPTO patents in recent years, almost 152,000 out of a total of more than 300,000 in 2016.
- The number of U.S. university patents granted by USPTO continues to increase rapidly, more than doubling between 2008 and 2016, reaching more than 6,600 in 2016.
- The number of foreign university patents granted by USPTO more than quadrupled during this same period, reaching more than 4,200 in 2016.
- Inventors in the United States received nearly half of USPTO patents granted in 2016. Japan and the European Union (EU) were the second and third largest recipients.
    - The share of USPTO patents granted to U.S. inventors declined from 51% in 2006 to 47% in 2016.

    - Faster growth in the number of USPTO patents granted to non-U.S. inventors was led by South Korea, China, and India over the same period.

- USPTO patents by U.S. inventors are relatively more concentrated in six advanced and science-based technologies, including three in the chemistry and health category—medical technology, pharmaceuticals, and biotechnology.
- USPTO patents by EU inventors are concentrated in nine technologies that are closely related to chemistry and health, including pharmaceuticals and biotechnology.
- Japan's USPTO patents are relatively more concentrated in two information and communications technologies—semiconductors and telecommunications—and in optics, surface technology and coating, and materials and metallurgy.

Knowledge Transfer Is an Essential Capacity of the National Innovation System

Technology transfer is "the process by which technology or knowledge developed in one place or for one purpose is applied and used in another place for the same or different purpose." Scientific discoveries and inventions flow into economic activity through freely accessible dissemination (e.g., open scientific and technical literature, person-to-person exchanges) and market-based transactions (e.g., patent licensing, formal collaborative R&D relationships that provide intellectual property protections, use of copyrighted materials). Organizations in academia, government, business, and nonprofit sectors all have policies and activities directed at identifying new knowledge and technology and helping transfer them where they can be applied, further developed, and eventually commercialized as new products and processes.

The federal government has been particularly active since the early 1980s in establishing policies and programs to improve the transfer and economic exploitation of the results of federally funded R&D—particularly through the Bayh–Dole Act of 1980 (affecting federally funded R&D in academia) and the Stevenson-Wydler Technology Innovation Act of 1980 and subsequent amplifying legislation (promoting technology transfer activities by the nation's federal laboratories). Most statistics on technology transfer concern these federal government technology transfer policies, as they operate through U.S. higher education institutions and U.S. federal laboratories. Less is known about the technology transfer that happens within the private or nonprofit sectors.

- In the higher education sector, invention disclosures filed through university technology management and transfer offices totaled 22,507 in 2015, up from 13,718 in 2003.
- University applications for U.S. patents also increased over time: 13,389 in 2015, nearly doubling from 7,203 in 2003.
- The number of U.S. patents awarded to universities remained flat between 2003 and 2009, and then rose to 6,164 in 2015.
- Active licenses that generated revenue from university inventions increased from 18,845 in 2001 to 40,402 in 2015.
- Business startups from university technology transfer reached 950 in 2015, with the number of past startups still operating that year at 4,757.
- For the U.S. federal laboratories (including federal agency intramural R&D facilities and federally funded research and development centers), invention disclosures totaled 5,103 in 2014, compared with 5,106 in 2003. Other trends in U.S. federal laboratories included the following.
    - A total of 2,609 patent applications were filed in 2014, compared with 2,318 in 2003.

    - The number of patents issued was 1,931 in 2014, compared with 1,631 in 2003.
    - The total of active invention licenses (mainly of patents) across all the federal laboratories was 3,956 in 2014, compared with 3,747 in 2003.
    - Active licenses for other intellectual property (i.e., other than patents, including copyrights) totaled 16,866 in 2014, compared with 2,771 in 2003.
- Cooperative R&D agreements (CRADAs) between federal laboratories and nonfederal partners (e.g., with businesses, nonprofit organizations, and other nonfederal organizations) totaled 9,180 in 2014, up from 5,603 in 2003. Other types of collaborative R&D relationships (the authorities for which vary by the agencies; e.g., relationships through the National Aeronautics and Space Act of 1958) totaled 27,182 in 2014, compared with 8,162 in 2003.
- Most of the federal agencies engage in all these technology transfer mechanisms, although the emphases vary. Some are particularly intensive in patenting and licensing activities; others are intensive in transfer through collaborative R&D relationships.
- Some agencies have unique transfer authorities (statutory) that can confer practical advantages (e.g., the National Aeronautics and Space Administration [NASA] through the National Aeronautics and Space Act of 1958; the U.S. Department of Agriculture [USDA], with a variety of non-CRADA mechanisms for cooperative R&D; the Department of Energy [DOE], whose contractor-operated laboratories and nonfederal staff can use copyrights to protect and transfer computer software).
- The federal agencies accounting for the largest portion of federal R&D—including USDA, the Department of Commerce (DOC), the Department of Defense (DOD), the Department of Homeland Security (DHS), the U.S. Department of Health and Human Services (HHS), and NASA—account for most of the technology transfer activities enabled by the Stevenson-Wydler Act.
- U.S. business sector–based researchers produced more than 50,000 peer-reviewed publications in 2016. Almost half were coauthored with university researchers, and 12% were coauthored with federal agency researchers.
- Technology licensing and other global exports of intellectual property in trade flows were $272 billion in 2016. Together, the United States, Japan, and the EU account for more than 80% of this total.

Venture Capital Investment Supports the Commercialization of Emerging Technologies

Access to financing is an essential component of the translation of inventions to innovations, both for new and growing firms. The difficulty of entrepreneurs obtaining financing contributes to the "valley of death," the inability of new and nascent firms to obtain financing to commercialize their inventions and technology. Venture capital investment also supports product development and marketing, company expansion, and acquisition financing.

- Venture capital investment, an indicator of support for the commercialization of emerging technologies, was more than $130 billion globally in 2016.
- The United States attracts slightly more than half of this venture capital funding. Four industries—software as a service, mobile, life sciences, and e-commerce—received the largest amount of U.S. venture capital investment between 2011 and 2016.
- China is the second largest recipient, attracting about one-quarter of the venture capital funding. Venture capital investment in China soared from $3 billion in 2013 to $34 billion in 2016, the fastest increase of any economy.

Federal Policies and Programs Have Been Implemented over the Past Several Decades to Reduce Characteristic Barriers to Innovation

In response to ongoing national concerns about the comparative strength of U.S. industries and their ability to succeed in the increasingly competitive global economy, the federal government has been active since the late 1970s in establishing policies and programs directed at strengthening the prospects for the development and flow of early-stage technologies into the commercial marketplace, particularly where the R&D has been federally funded.

- Federal funding to small entrepreneurial companies engaged in R&D with eventual commercialization objectives, through the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs, are now considerably larger than when these programs were first initiated in, respectively, the early 1980s and the mid-1990s.
- At its start in FY 1983, the SBIR program (across all participating agencies) made 789 awards (all Phase I) for a total of $38 million in funding; in FY 2015, 4,508 awards were made (Phase I and Phase II), with funding totaling $1.923 billion.
- The STTR program started in FY 1995, with a single Phase I award for $100,000. In FY 2015, 725 STTR awards were made (Phase I and Phase II), with funding totaling $258 million.
- Beyond the well-known SBIR and STTR programs, which apply across much of the federal government, some departments or agencies have their own early-stage development programs more narrowly directed at their mission objectives. Examples of these programs are the DOC National Institute for Standards and Technology's (NIST's) Hollings Manufacturing Extension Partnership, DOE's Advanced Research Projects Agency—Energy, and the National Science Foundation's (NSF's) Industry–University Cooperative Research Centers Program (IUCRC). (An appendix table to the chapter identifies a larger set of these programs across the USDA, DOC, DOD, DOE, HHS, DHS, Department of Transportation, Environmental Protection Agency, NASA, and NSF.)

Innovation Takes Place in Manufacturing, Services, and Other Industries

Indicators of innovation in firms—the implementation of a new or significantly improved product or business process—show that information and communications technology (ICT)-producing industries report many of the highest rates of innovation. These indicators are collected in survey data guided by The *Oslo Manual* of the Organisation for Economic Co-operation and Development (OECD) and Eurostat (2005).

- One in six U.S. firms (17%) introduced a new or significantly improved product or process between 2013 and 2015, according to the Business R&D and Innovation Survey (BRDIS).
  - U.S. manufacturing industries see highest rates of innovation in computer and electronic products (57%) and electrical equipment and components (48%).
  - U.S. nonmanufacturing industries see highest rates of innovation in computer systems design (44%), scientific R&D services (44%), electronic shopping and auctions (40%), and information (31%).

Economic Impacts of Innovation Are Indirectly Measured, and Show Slowing Growth

Impacts of innovation are understood in multiple ways, and economic indicators are a partial but quantifiable measure. Multifactor productivity, the output growth that cannot be attributed to labor and capital inputs, is a broad measure of

the impact of innovation and technological change on the economy. It shows declining growth in the United States compared with the 2000s and earlier decades. This is true for the United States and for many other economies. Small, fast-growing firms in the United States, which are a measure of entrepreneurship and its associated job growth, have shown a declining rate of new firm formation since the early 2000s.

Introduction

Invention, knowledge transfer, and innovation are distinct but interrelated components of a complex system for transforming creativity and knowledge from S&E into benefits to society and the economy. Scientific discovery, as extended and amplified by applied research and development, increases the storehouse of knowledge available for further transformation. Invention and innovation draw from this resource.

A complete picture of the innovation process is multidimensional. It requires indicators on actors, as individuals and through institutions that include businesses, government, academia, and nonprofit institutions. Inputs to innovation also include physical capital and infrastructure, both public and private, intangible capital, and publicly available knowledge. Innovation incidence provides an indicator of commercialization through the business sector. Beyond incidence, indicators of the impact of innovation presented here focus on two economic impacts, productivity growth and firm growth.

Chapter Overview

Invention brings something new into being and has a practical bent—the production of a new process or product that is potentially useful, previously unknown, and nonobvious. Invention contrasts with the focus of scientific research that leads to *discovery*—knowledge about existing phenomena that previously were unknown. In practice, inventions and scientific discovery often interact with each other: solving a practical problem may require the application of basic science not yet discovered, whereas scientific discovery may yield unanticipated applications that lead to potentially useful products and processes. In this chapter, we present data on inventions as represented by patents, along with information about their sources. See sidebar Key Terminology for descriptions of key terms used in this chapter.

SIDEBAR

Key Terminology

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

U.S. Patent and Trademark Office (USPTO) patent: A property right granted by the U.S. government to an inventor "to exclude others from making, using, offering for sale, or selling the invention throughout the United States or importing the invention into the United States" for a limited time in exchange for public disclosure of the invention when the patent is granted.*

Knowledge transfer: The process by which technology or knowledge developed in one place or for one purpose is applied in another place for the same or a different purpose. This transfer can occur freely or through exchange, and deliberately or unintentionally.

Innovation: The implementation of a new or significantly improved product (good or service) or process, a new marketing method, or a new organizational method in business practices, workplace organizations, or external relations. External relations include collaborations with other institutions, including customers, and first-time outsourcing or subcontracting (Organisation for Economic Co-operation and Development [OECD] 2005).

Innovation activities: All scientific, technological, organizational, financial, and commercial steps that actually lead, or are intended to lead, to the implementation of innovations. These steps include R&D, acquisition of external knowledge and capital equipment, market preparation, development of new organizational methods, and design activities (OECD 2005).

Economic impacts of innovation: The effects of innovations and innovation activities on business activities, economic output, employment, and standard of living.

* This is the USPTO definition, found on the USPTO website at https://www.uspto.gov/learning-and-resources/glossary#sec-p, accessed 15 June 2017.

The transition from potential to realized usefulness for discoveries and inventions generally involves other actors besides scientists, engineers, and inventors. The discoveries and inventions must somehow be envisioned as useful and then adapted and adopted into practice and into circulation in the economy. This process frequently involves the transfer of science and technology (S&T) to businesses, government entities, universities, other organizations, and individuals for further development and eventual commercial and otherwise useful applications. Indicators for these activities include licensed inventions, citations, cooperative agreements, and collaborations. Other aspects of this transfer take place directly between individuals as they interact at work and less formally. Although harder to identify, this less formal or tacit transfer of technical knowledge is also an important dimension.

The creation of new products and processes through innovation is a key goal for many nations. According to the Organisation for Economic Co-operation and Development (OECD), common policy objectives for innovation include sustainable economic growth; good-quality jobs; an increased standard of living, and addressing key health, environmental, and social challenges (OECD 2014, 2016). Many countries envision enhancing firm-based innovation and entrepreneurship as key paths toward those goals. These paths intersect as entrepreneurs start new firms that create new products and introduce new processes. Although different stakeholders emphasize different aspects of innovation, there has been broad consensus that S&T policy and economic policy at the national level should encourage and support innovation, with economic growth and advancements in knowledge as important justifications for increased investment in S&T.

The longer-term impacts of the innovation process are often the ultimate targets of interest. These impacts emerge as knowledge, inventions, and innovations diffuse through society. They include those that are desired, such as sustainable economic growth, good-quality jobs, an increased standard of living, environmental quality, and addressing broader societal challenges. The innovation process has the potential for other, and less desirable, outcomes as well. The latter may include rapid obsolescence of some job skills, increased inequality across regions and groups of people, the vulnerability of systems to attacks, and ethical issues raised by new technologies.

Identifying when innovation has taken place and its impacts presents measurement challenges; these challenges are present in other hard-to-measure outputs, such as those that result from public and private spending on health care or education.[1] While business surveys provide indicators of product and process innovation for many firms, the data as yet present an incomplete picture of innovation output and its economic impact. The result is frequent use of innovation-related inputs, such as employment of scientists and engineers, or innovation-related activities, such as R&D and patenting, as indicators of innovation.

A quantifiable and comparable economic impact metric for innovation is multifactor productivity (MFP). MFP is an economic efficiency measure calculated as the output growth that cannot be attributed to labor and capital inputs, after accounting for changes in workforce skill and the quality of capital. Estimated from national economic accounts data, it is an indicator of overall technological change in a sector or economy. However, MFP is also affected by the timing between innovation and its widespread adoption, complicating inferences about the pace of innovation.

This measurement challenge, along with the breadth of policy interest in innovation and the factors that influence it, shapes the choice of indicators presented in this chapter. For each of the three topics covered in this chapter, invention, knowledge transfer, and innovation, the section includes a brief discussion of the gap between the data available and the indicator desired.

The innovation-related data in this chapter complement the data on human capital and market activity presented in previous chapters in this report. The chapters of *Science and Engineering Indicators 2018* touch on many topics that feed into this system, such as the S&E workforce, the role of universities, and R&D activity. In this system human, physical, and intangible capital interact through activities that include R&D, invention, and production.

The outputs from these activities can be knowledge capital, inventions, publications, or research tools, or new products, services, or ways of doing business. The systems framework for studying innovation recognizes that there may be significant feedback mechanisms, often complex and numerous, and such mechanisms magnify the ultimate impact of innovation activities. Scientific discoveries and inventions can be used repeatedly, and scientists and engineers add to their human capital through their discoveries. As knowledge and human capital accumulate and are widely used, many new discoveries and innovations build on those that came before.

These activities take place in a complex environment that includes the availability of financing for innovation, public infrastructure, the tax and regulatory environment, intellectual property protection, social attitudes toward risk, and relationships across institutions.

Chapter Organization

This chapter is organized into three principal sections on the following discussion topics. Invention is discussed in the first section, and patenting data are shown for the U.S. Patent and Trademark Office (USPTO) by sector and by technology area. The knowledge transfer section of the chapter provides data on technology transfer activities of academic institutions and the federal government, invention disclosures, patenting, licensing, and collaborative R&D agreements. Data are presented on citations within patent documents to peer-reviewed literature and to coauthorships between businesses and authors from other sectors. For greater detail on bibliometric indicators, see Chapter 5 section Outputs of S&E Research: Publications. The final section, on innovation, provides data on venture capital funding, government policies and programs to encourage early-stage development, survey-based indicators of innovation incidence in business, and measures of the economic impact of innovation—productivity and trends in the number and employment effects of small and fast-growing firms.

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[1] Although indicators are always partial measures of the concepts in which we are interested, this is particularly true with innovation. The output can be intangible and often unique, and although products created by innovation are produced and sold in the market, process and organizational innovations are hard to identify and to distinguish from trivial improvement.

Invention: United States and Comparative Global Trends

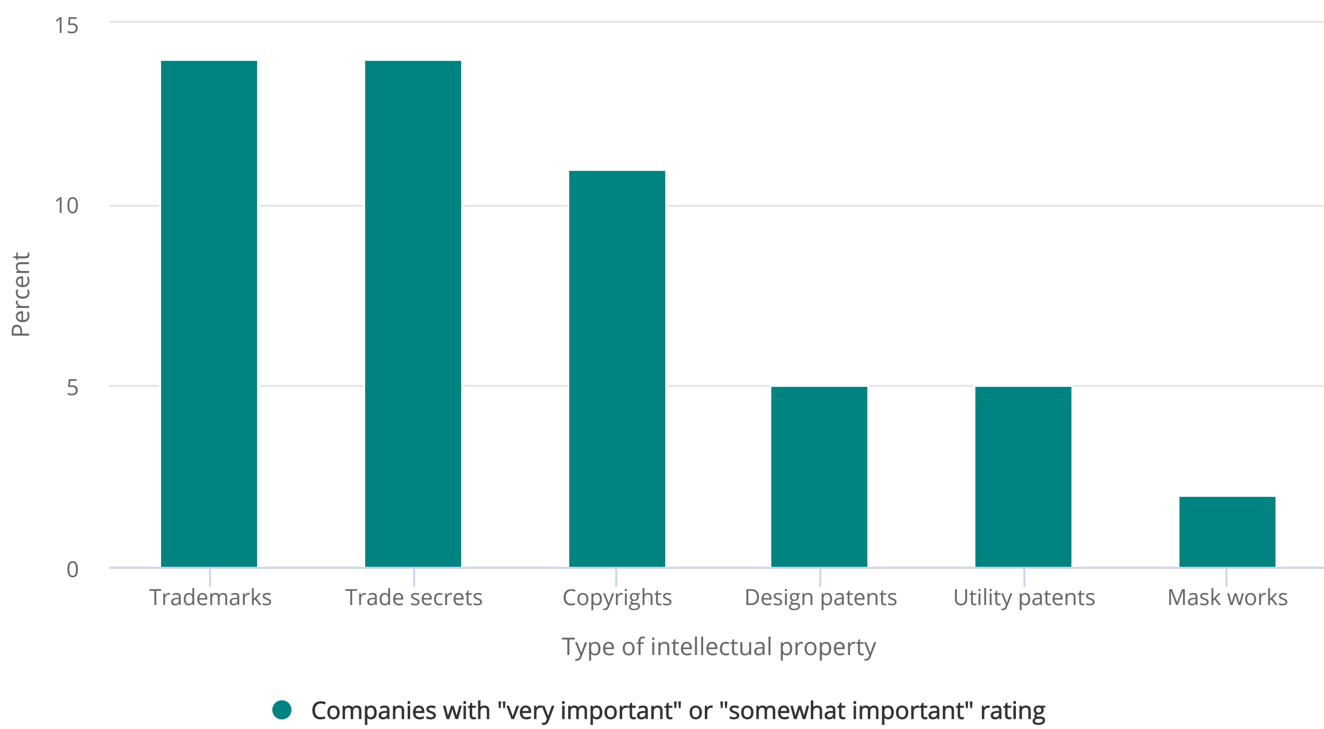
Inventions and the pace of their emergence are critical features of a national innovation system. Invention is the creation of new, useful, and nonobvious goods, services, and processes and is an important source of the innovations that eventually emerge in the marketplace or other practical use. Some of these may be described in scientific papers, which provide a means for researchers to claim credit and disseminate the results of their discoveries.

Patents serve a different purpose. Inventors often have economic motivations to keep the details of their inventions secret. The patenting system provides the legal right for a limited time to exclude others from making, using, offering for sale, or selling the invention, in exchange for public disclosure of the technical information in the granted patent. Extensive publicly available administrative data exist for patents and their inventors, and extensive databases allow for systematic insights into these patents. In the absence of other comprehensive data on invention, patent data provide unique and useful insights into the inventions deemed valuable enough to patent. However, analysis of these data requires caution.

One caveat is that most patented inventions are never commercialized; they are neither representative of all inventions nor are they measures of innovation. Many valuable inventions that are commercialized are not patented. Companies choose a variety of strategies to protect their inventions and intellectual property. For example, U.S. companies rate trade secrets higher than patents in their importance for protecting intellectual property (Figure 8-1), which is true even for R&D-performing firms.[1]

FIGURE 8-1

For companies that performed or funded R&D, shares rating intellectual property as being very or somewhat important: 2011



Note(s)

A mask work is a two- or three-dimensional layout or topography of an integrated circuit on a semiconductor that is protected under U.S. intellectual property law.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Business R&D and Innovation Survey (BRDIS), 2011.

Science and Engineering Indicators 2018

In addition, patent protection may be sought for reasons other than intended commercialization. Privately owned patents may be obtained to block rivals and negotiate with competitors, to use in lawsuits, or to build “thickets” of patents to impede or raise others’ costs of R&D and innovation (Cohen et al. 2000). Research suggests that some organizations and countries pursue “strategic patenting” to block competitors and to monetize patents through licensing and other activities (Ernst 2013:1–9). Other firms may respond by patenting defensively. New and emerging firms may seek patent protection to help obtain financing because investors perceive patents as potentially valuable for a firm’s assets and future profitability. Finally, cross-country analysis indicates that international differences in taxes on corporate and patent income influence the choice of patent location for multinational firms (OECD 2016:3). However, within these limitations, USPTO patent documents tell us when and in what technology areas inventors have decided to protect their intellectual property with patent protection. This rich detail, which also includes the name and address of the inventor and assignee, justifies their presentation. U.S. patents are issued to provide protection to inventions in the U.S. market. Foreign owners account for more than half of USPTO patents in recent years, 152,000 out of a total of slightly more than 300,000 patents granted in 2016 (Appendix Table 8-1). The USPTO reports the five organizations awarding the highest numbers of patents in 2015 as IBM, Samsung, Canon, Qualcomm, and Google (USPTO 2017).

USPTO Patenting Activity

As described previously, the purpose of patenting is to allow inventors to gain the economic benefits of their inventions in exchange for disclosure of technical information about the invention. Most patenting takes place in the business sector. Motivations differ substantially from the motivation of authors of peer-reviewed literature, where original contributions to publicly available knowledge may benefit reputation and career advancement without a direct financial benefit for the authors. Business researchers are also more likely to be engaged in experimental development activity than their academic and government counterparts (see Table 4-4 in Chapter 4), suggesting more opportunities for direct commercial applications of their work.

USPTO patents provide data on the inventor and the owner of the patent (known as the assignee). The data described in the next several paragraphs are based on the economic sector of the patent owner. In 2016, 151,000 USPTO patents were assigned to U.S. owners (Appendix Table 8-1). Among these U.S. owners, the private sector (for-profit companies) by far receives the most patents (85% share). Individuals receive the next largest share (9%), followed by the academic sector (4%). The government sector receives a small share of patents (1%), reflecting in part the focus of government entities on activities other than the protection of intellectual property, as well as a small number of U.S. government patents whose contents may reveal sensitive security information. The nonprofit sector, which is included in the “other” category, receives a very small share of patents (0.3% or less). Over the last decade, the private sector’s share of U.S. patents slightly increased from 82% to 85%. Although the individual share declined from 13% to 9%, continuing a long-term trend away from individual patenting, almost 13,600 patents were granted to individual U.S. owners in 2016.

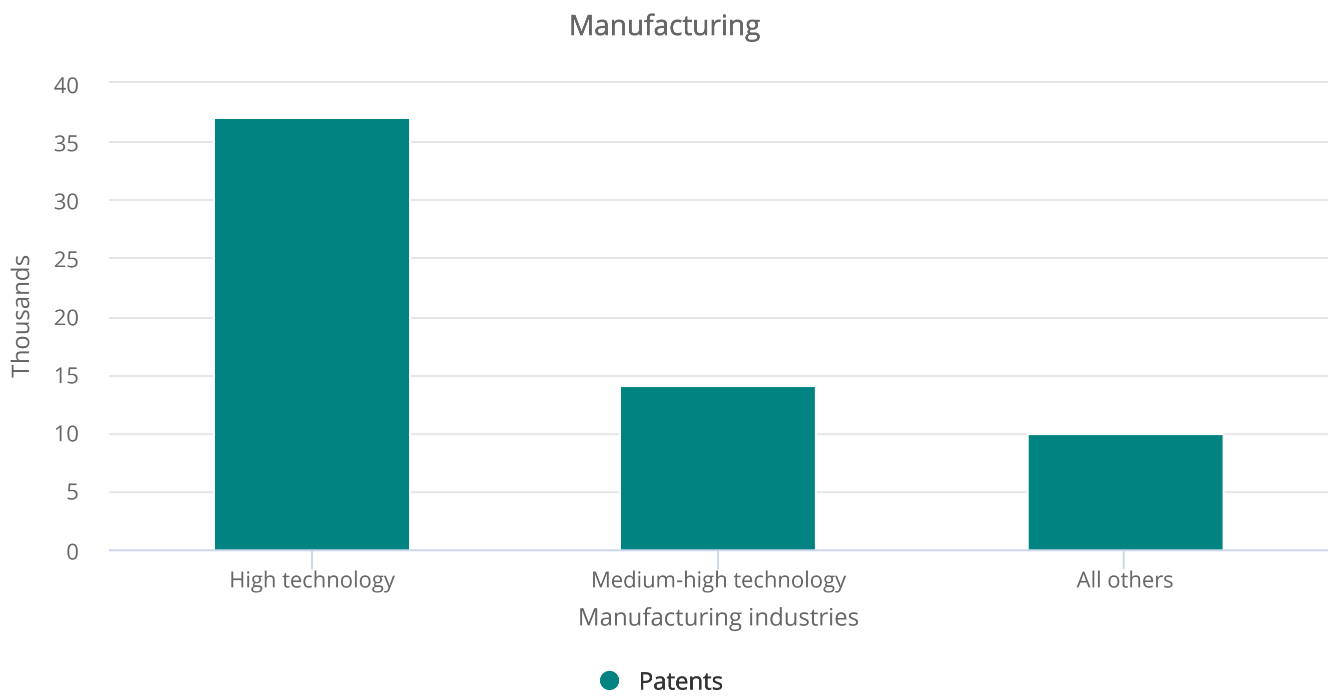
Patenting by U.S. Industries

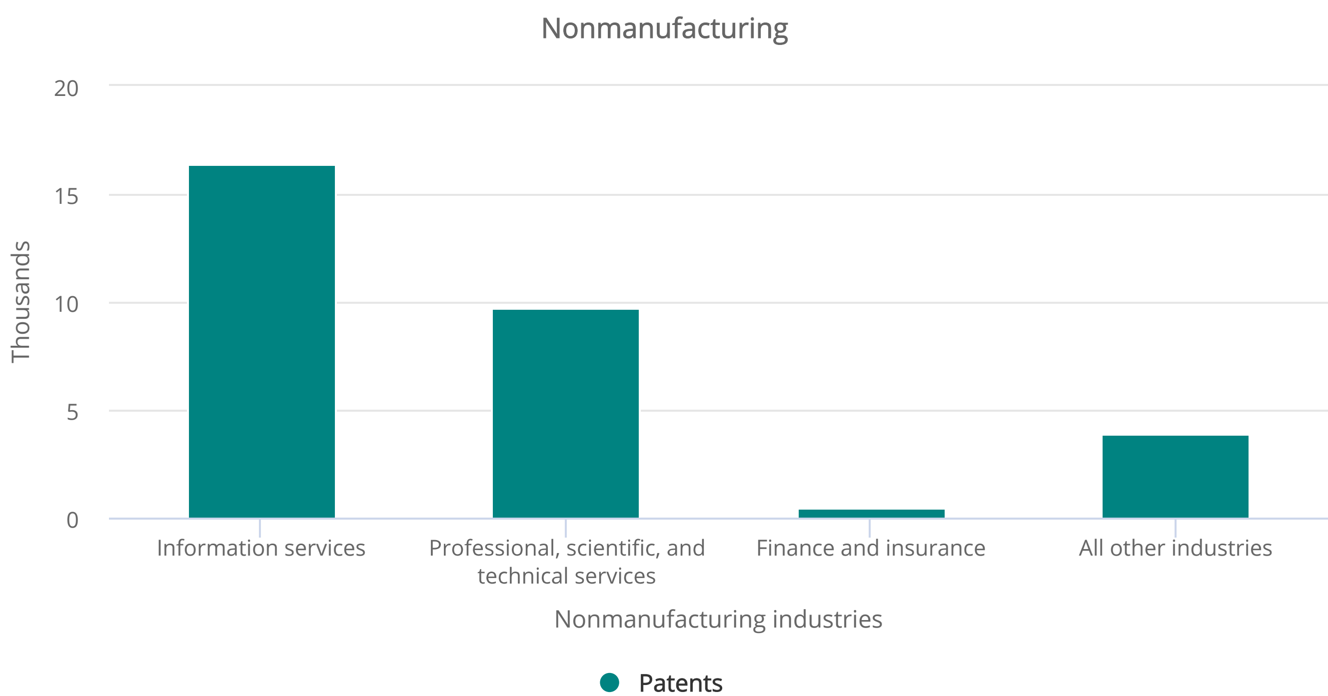
USPTO data provide information about the technology area for the patent but not the industry in which the inventor or assignee works. Industry-level measures of patenting are available for a more limited set of firms, those in scope for the National Science Foundation (NSF) National Center for Science and Engineering Statistics Business R&D and Innovation Survey (BRDIS), which focuses on the activity of R&D-performing firms. BRDIS data estimate that more than 91,000 patents were issued to R&D performing firms in the United States in 2015. The U.S. knowledge- and technology-intensive industries described in Chapter 6—high-technology manufacturing, medium-high technology manufacturing, and commercial knowledge-intensive services industries—have a far larger share of patents than other industries (Figure 8-2). U.S. high-technology manufacturing industries received 61% of the 61,000 USPTO patents granted to U.S. manufacturing industries in 2015. Medium-high technology manufacturing industries received almost a quarter of these patents. Together, these industries accounted for more than 80% of all patents granted to U.S. manufacturing industries in 2015.

U.S. commercial knowledge-intensive services received 87% of the 30,000 patents granted to nonmanufacturing industries in 2015 (Figure 8-2). The information services industry accounted for 16,000 patents, 62% of the patents granted to commercial knowledge-intensive services; the professional, scientific, and technical services accounted for almost 10,000 patents (37%).

FIGURE 8-2

USPTO patents granted, by selected U.S. industry: 2015





USPTO = U.S. Patent and Trademark Office.

Note(s)

High-technology manufacturing industries include aerospace, communications, computers and office machinery, pharmaceuticals, semiconductors, and testing, measuring, and control instruments. Medium-high-technology manufacturing industries include chemicals excluding pharmaceuticals, motor vehicles and parts, electrical equipment and appliances, machinery and equipment, and railroad and other transportation equipment. Detail may not add to total because of rounding. Industry classification is based on the dominant business code for domestic R&D performance, where available. For companies that did not report business codes, the classification used for sampling was assigned. Statistics are based on companies in the United States that reported to the survey, regardless of whether they did or did not perform or fund R&D. These statistics do not include an adjustment to the weight to account for unit nonresponse. For a small number of companies that were issued more than 100 patents by USPTO, survey data were supplemented with counts from https://www.uspto.gov/, accessed 20 January 2017.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Business R&D and Innovation Survey (BRDIS), 2015.

Science and Engineering Indicators 2018

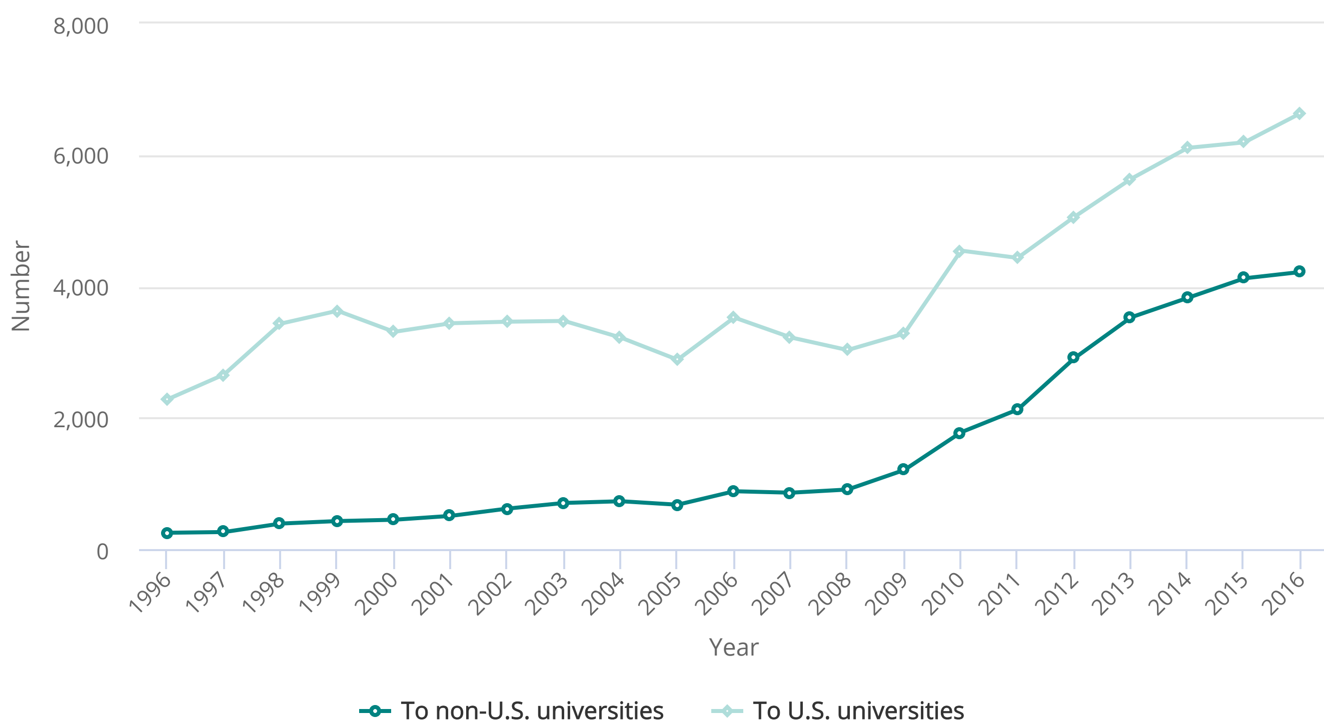
Trends and Patterns in Academic Patenting

Compared with the production of S&E publications (as described in Chapter 5 section Outputs of S&E Research: Publications) patenting is a less-frequent event. For example, in 2016, 409,000 S&E publications were produced by U.S.-affiliated authors, almost 308,000 of these from U.S. academic authors (Appendix Table 5-41). By contrast, in the same year, 151,000 USPTO patents were assigned to U.S. owners (Appendix Table 8-1), and 6,600 of these patents were assigned to U.S. academic owners (Appendix Table 8-2).

These U.S. patents, together with 4,200 patents granted to foreign universities and colleges in 2016, account for just under 11,000 academic patents. Foreign universities have expanded patenting rapidly since 2008, when 900 were granted (Figure 8-3).

FIGURE 8-3

USPTO patents granted to U.S. and non-U.S. academic institutions: 1996–2016



USPTO = U.S. Patent and Trademark Office.

Note(s)

Patents are allocated according to patent ownership information. Patents are credited on a fractional-count basis (i.e., for articles with collaborating institutions, each institutions receives fractional credit on the basis of the proportion of its participating institutions). The sum of patents granted to non-U.S. and U.S. academic institutions is lower than the total number of patents granted to academic institutions as country affiliation of a few academic patents is unknown (data not presented).

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; PatentsView; U.S. Patent and Trademark data, accessed April 2017.

Science and Engineering Indicators 2018

In a detailed examination of the USPTO data for 2009 to 2014, Leydesdorff, Etzkowitz, and Kushnir (2016) attribute the rapid growth in foreign university patenting to universities in Taiwan, South Korea, Japan, and China. They also found that universities in Saudi Arabia, Norway, and India experienced particularly rapid growth from a small base. The authors found that, unlike the long-term biomedical focus of European and U.S. university patenting, electronics patents are the focus of much of the recent growth in foreign university patents.

Patent data filings include detailed information on technology area, allowing for analysis of trends in patenting over time. The patent indicators described below are classified by technology areas from the World Intellectual Property Organization

(WIPO), summarized into 35 technical fields shown in Appendix Table 8-2 for U.S. university patents for 1996–2016. In 2016, slightly more than half (54%) of all the patents granted to universities were in just 5 of the 35 technical fields: pharmaceuticals, biotechnology, medical technology, organic fine chemistry, and measurement (Table 8-1). For technical areas with more than 100 academic patents, the annual growth rate for 2016 was highest for digital communications (11.1%), microstructural and nanotechnology (9.3%), and computer technology (8.3%).

TABLE 8-1

U.S. university patent awards, by technology area: 2002 and 2016

(Number and percent)

Rank	Technology area	2002	2016	Average annual change (%)	2016 share (%)
-	All university patents	3,461	6,639	4.8	100
1	Pharmaceuticals	575	1,008	4.1	15.2
2	Biotechnology	710	953	2.1	14.4
3	Medical technology	236	683	7.9	10.3
4	Organic fine chemistry	295	480	3.5	7.2
5	Measurement	216	438	5.2	6.6
6	Computer technology	119	406	9.2	6.1
7	Analysis of biological materials	143	296	5.3	4.5
8	Electrical machinery, apparatus, energy	87	264	8.3	4.0
9	Semiconductors	106	244	6.1	3.7
10	Chemical engineering	70	178	6.9	2.7
11	Optics	140	175	1.6	2.6
12	Microstructural and nanotechnology	65	143	5.7	2.1
13	Basic materials chemistry	51	139	7.4	2.1
14	Macromolecular chemistry, polymers	77	131	3.8	2.0
15	Digital communication	25	113	11.3	1.7
16	Materials, metallurgy	62	111	4.3	1.7
17	Other special machines	78	94	1.3	1.4
18	Surface technology, coating	56	87	3.2	1.3
19	Telecommunications	50	85	3.9	1.3
20	Audio-visual technology	37	79	5.6	1.2
21	Engines, pumps, turbines	25	63	6.8	0.9
22	Basic communication processes	20	62	8.4	0.9
23	Environmental technology	43	56	1.9	0.8
24	Control	22	54	6.6	0.8

Rank	Technology area	2002	2016	Average annual change (%)	2016 share (%)
25	Food chemistry	28	41	2.7	0.6
26	Civil engineering	18	36	4.9	0.5
27	Textile and paper machines	20	32	3.6	0.5
28	Transport	16	29	4.4	0.4
29	Mechanical elements	19	27	2.6	0.4
30	Other consumer goods	9	25	7.9	0.4
31	Handling	7	21	7.9	0.3
32	Thermal processes and apparatus	10	19	4.5	0.3
33	IT methods for management	3	19	15.0	0.3
34	Machine tools	17	17	0.2	0.3
35	Furniture, games	4	17	10.7	0.2
36	Unclassified	1	13	19.8	0.2

IT = information technology.

Note(s)

Patents are allocated according to patent inventorship information. Data include institutions affiliated with academic institutions, such as university and alumni organizations, foundations, university associations, and affiliated hospitals. Universities vary in how patents are assigned (e.g., to boards of regents, individual campuses, or entities with or without affiliation with university). Patents are classified under the World Intellectual Property Organization classification of patents, which classifies International Patent Classification codes under 35 technical fields. Fractional counts of patents were assigned to each technological field on patents to assign the proper weight of a patent to the corresponding technological fields under the classification. For instance, a patent that is classified under five different technological fields will see each of its technological fields receive a 0.2 count of the patent so that the patent accounts for a count of 1.0 across all technological fields. Data across technical fields sum up to the total number of granted academic patents in the United States and also sum up to the total number of U.S. Patent and Trademark Office (USPTO) patents granted to academic institutions. See Appendix Table 8-2 for more years of data.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; USPTO patent data, accessed April 2017.

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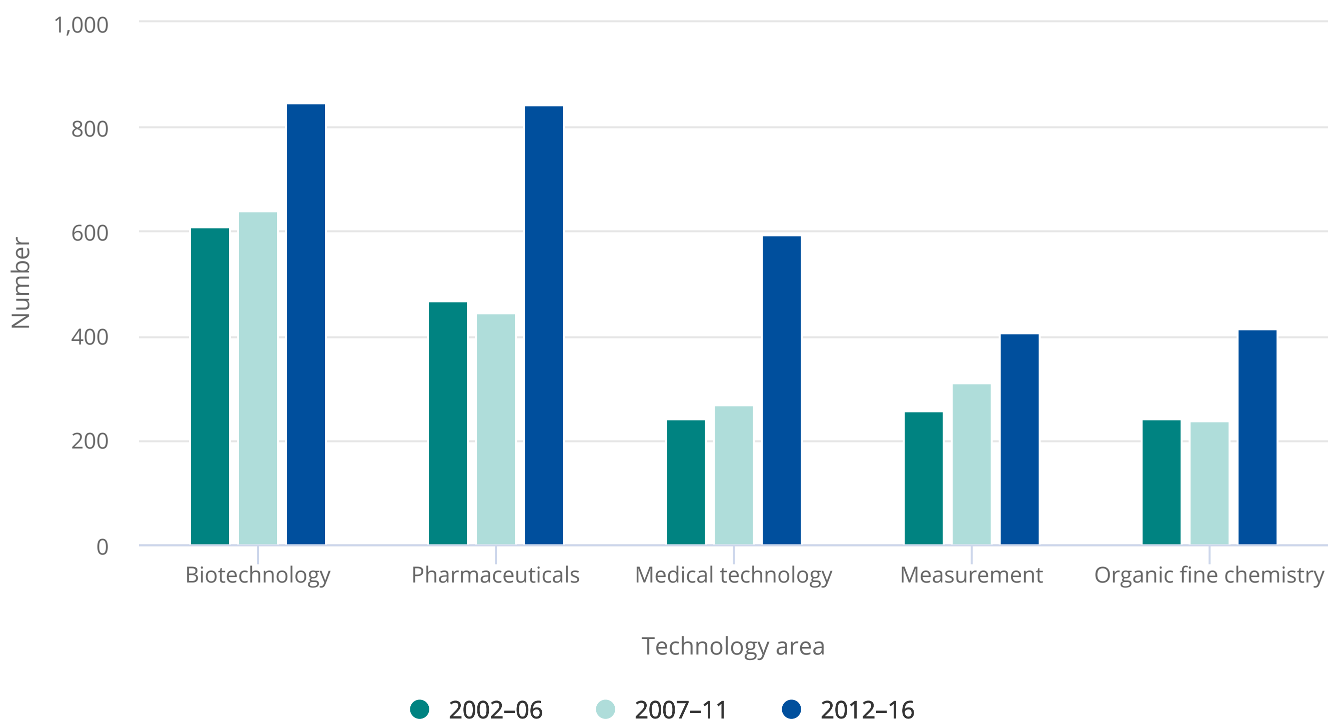
In 2016, just 5 of the 35 technical fields, pharmaceuticals, biotechnology, medical technology, organic fine chemistry, and measurement, accounted for slightly more than half (54%) of all the patents granted to universities (Table 8-1). Academic patenting data from USPTO are presented in 35 World Intellectual Property Organization (WIPO) technical fields shown in Appendix Table 8-2. The table shows patent awards for U.S. university patents for 1996–2016.

Although the pharmaceuticals field had the highest number of university patents in the most recent year for which we have data, 1,008 patents in 2016, this reflects a relatively recent trend. Over a longer period since the turn of the century, biotechnology patents had accounted for the largest number of U.S. university patents: Figure 8-4 shows the top five areas for university patenting in 5-year averages between 2002 and 2016. Of these five technical fields, medical technology and measurement, consisting of measurement instruments, have shown continual growth over all three 5-year periods.

FIGURE 8-4

U.S. academic patents, by selected technology area, 5-year averages: 2002–16



Note(s)

Patents are allocated according to patent ownership information.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; PatentsView; U.S. Patent and Trademark Office patent data, accessed April 2017. See Appendix Table 8-2, which includes data for 35 technology areas.

Science and Engineering Indicators 2018

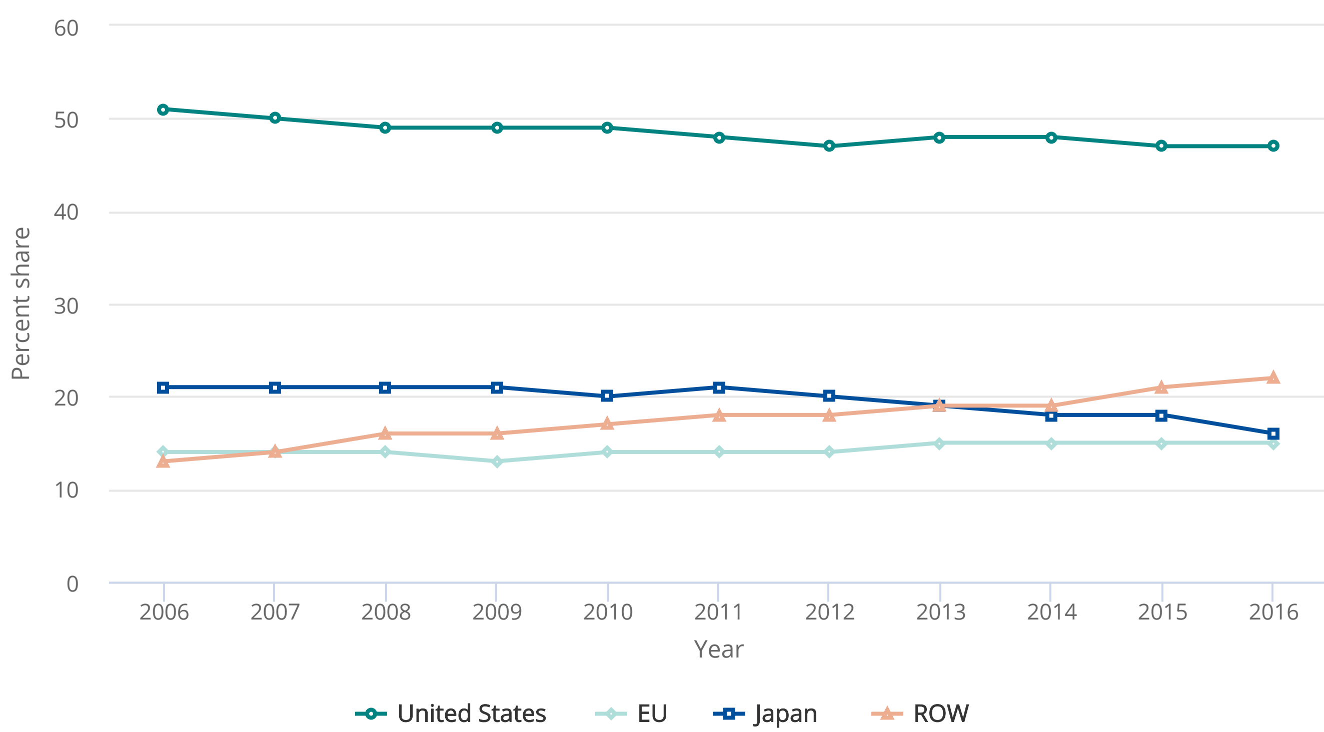
Global Patent Trends and Cross-National Comparisons

Global and Cross-National Activity in USPTO Patents

The data described in this section are based on the geographic address of the inventor. The USPTO granted more than 300,000 patents in 2016 to inventors all over the world (Figure 8-5; Appendix Table 8-3 and Appendix Table 8-4). The United States received nearly half (47%) of them, followed by Japan (16%) and the member countries of the European Union (EU) (15%). Although several developed and developing economies, including South Korea, China, Taiwan, and India, have seen steep increases over time in their USPTO patenting activity, the United States, the EU, and Japan together still account for the clear majority of USPTO patents (Figure 8-5).

FIGURE 8-5

USPTO patents granted, by selected region, country, or economy of inventor: 2006–16



EU = European Union; ROW = rest of world; USPTO = U.S. Patent and Trademark Office.

Note(s)

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

Source(s)

Science-Metrix; SRI International. See Appendix Table 6-37.

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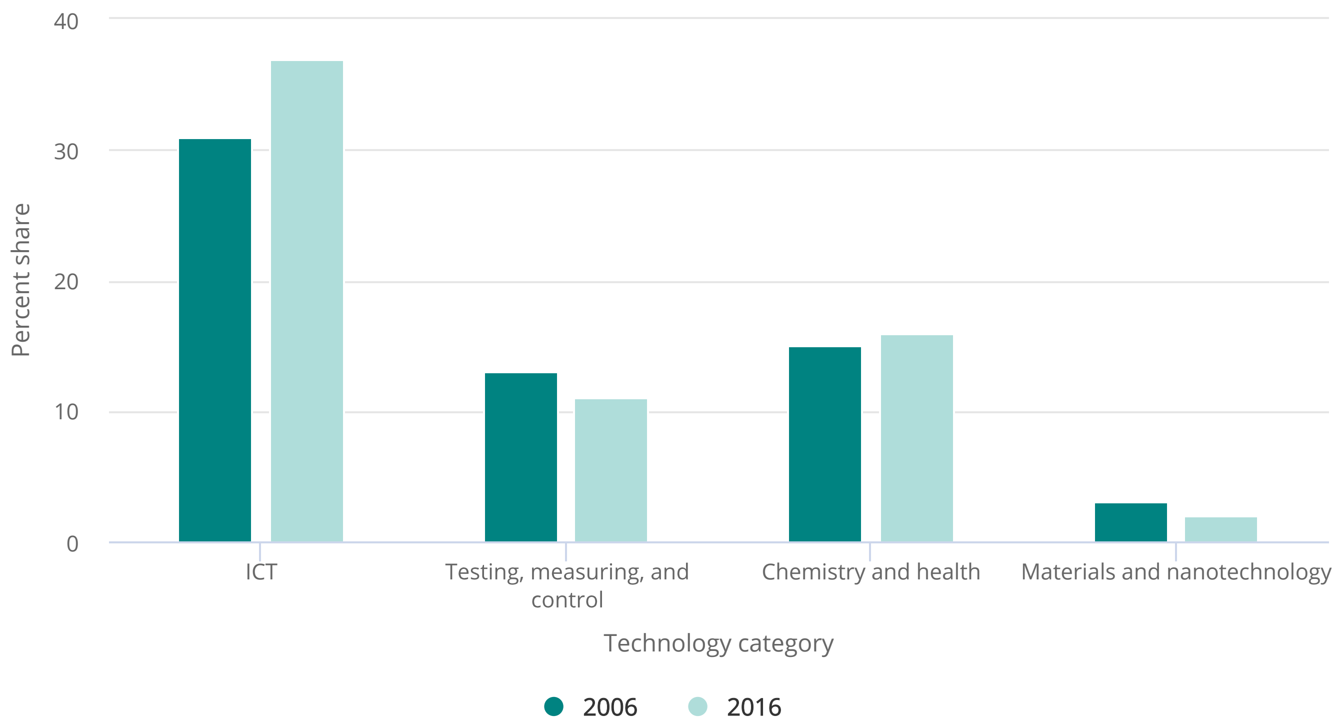
After flat growth for most of the 2000s, the number of USPTO patents grew more than 80% between 2009 and 2016, led by growth of patents in information and communications technologies (ICT) (Figure 8-6; Appendix Table 8-4 through Appendix Table 8-10).

Faster growth of patents granted to non-U.S. inventors reduced the U.S. share from 51% in 2006 to 47% in 2016 (Figure 8-5; Appendix Table 8-4). The increase in foreign patents reflects globalization, as foreign firms file their existing patents in multiple jurisdictions (Fink, Khan, Zhou 2015). Large multinational companies, including those based outside of the United States, are increasingly seeking patent protection beyond their domestic borders.

The pattern of this globalization of USPTO patents has been uneven. Japan's share fell, and the EU's share remained steady between 2006 and 2016 (Figure 8-5; Appendix Table 8-4). Patenting activity in the Asian economies of South Korea, China, and India increased strongly over the last decade (Figure 8-7; Appendix Table 8-4). South Korea's share doubled to reach 6%. China's patenting activity grew the fastest, although from a low base, resulting in its share rising from 1% to 4%. India also grew from a low base, with its share reaching 1%. Although the number of patents more than doubled between 2006 and 2016, Taiwan's global share remained at 4% during this period.

FIGURE 8-6

USPTO patents granted in selected broad technology categories: 2006 and 2016



ICT = information and communications technology; USPTO = U.S. Patent and Trademark Office.

Note(s)

Patents are classified under the World Intellectual Property Organization (WIPO) classification of patents, which classifies International Patent Classification (IPC) codes under 35 technical fields. IPC reformed codes take into account changes that were made to the WIPO classification in 2006 under the eighth version of the classification and were used to prepare these data. However, because PatentsView only provides the original IPC codes as they appeared on patents and not the IPC reformed codes, current Cooperative Patent Classification codes on patents were converted back to the most recent IPC classification to prepare these statistics. Fractional counts of patents were assigned to each technological field on patents to assign a proper weight of a patent to the corresponding technological fields under the classification. Patents are fractionally allocated among regions, countries, or economies based on the proportion of residences of all named inventors.

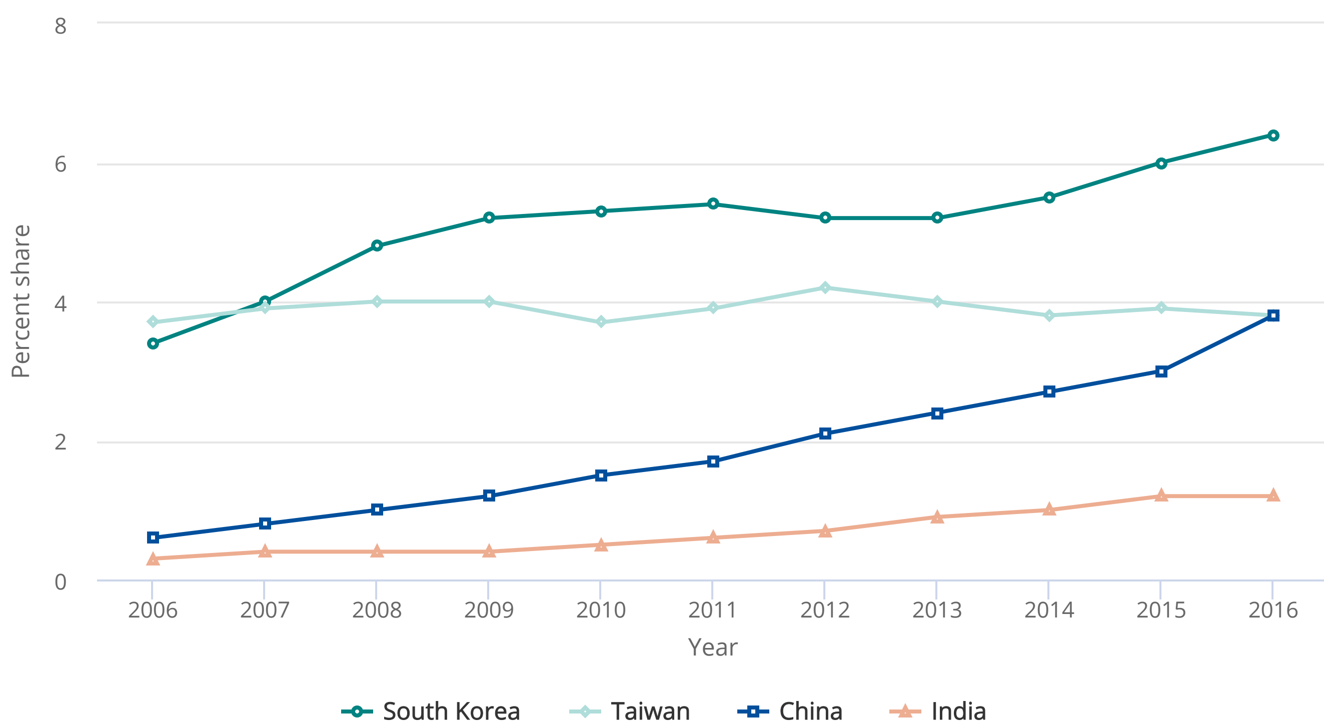
Source(s)

Science-Metrix; PatentsView; SRI International, accessed December 2016. See Appendix Table 6-37 through Appendix Table 6-48.

Science and Engineering Indicators 2018

FIGURE 8-7

USPTO patents granted, by selected country or economy of inventor: 2006–16



USPTO = U.S. Patent and Trademark Office.

Note(s)

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

Source(s)

Science-Metrix; LexisNexis; SRI International. See Appendix Table 6-37.

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Patenting in selected technologies

This section discusses patterns and trends of four technology categories that are closely linked to science or the knowledge- and technology-intensive industries described in Chapter 6: ICT; testing, measuring, and control; chemistry and health; and materials and nanotechnology (Table 8-2). The patent count data by country for some of the 35 WIPO patent fields shown in Appendix Table 8-2 are reorganized into these four broader categories. The ICT category, consisting of six technologies, has the largest share of USPTO patents (37% of all USPTO patents in 2016) (Figure 8-6). Patents granted in these fields are shown in Appendix Table 8-5 through Appendix Table 8-10. Of ICT, computer technology is the largest in terms of USPTO patent share (14%), followed by digital communication (10%), semiconductors (6%), and telecommunications (4%). The next largest category is chemistry and health (16%), consisting of seven technologies; medical technology has the largest share (6%) among these technologies. Patents granted in these fields are shown in Appendix Table 8-11 through Appendix

Table 8-17. The third largest (11%) is testing, measuring, and control, consisting of four technologies (Appendix Table 8-18 through Appendix Table 8-21). Materials and nanotechnology, consisting of three technologies, has a far smaller share (2%) (Appendix Table 8-22 through Appendix Table 8-24).

TABLE 8-2

Selected technology areas of USPTO patents

(Technology areas)

Broad category	Technology area
Information and communications technologies	Communication process
	Computer
	Digital communications
	Information technology methods for management
	Semiconductors
	Telecommunications
Testing, measuring, and control	Analysis of biological materials
	Control
	Measurement
	Optics
Chemistry and health	Pharmaceuticals
	Biotechnology
	Basic material chemistry
	Organic chemistry
	Macromolecular chemistry
	Chemical engineering
	Medical technology
Materials and nanotechnology	Materials and metallurgy
	Microstructural and nanotechnology
	Surface technology and coating

USPTO = U.S. Patent and Trademark Office.

Note(s)

Patents are classified under the World Intellectual Property (WIPO) classification of patents, which classifies International Patent Classification (IPC) codes under 35 technical fields. IPC reformed codes take into account changes that were made to the WIPO classification in 2006 under the eighth version of the classification.

Source(s)

Science-Metrix; PatentsView; SRI International.

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The number of ICT patents nearly doubled between 2006 and 2016, the fastest growth of these four technology categories. The ICT share of all patents increased from 31% to 37% during this period (Figure 8-6). For example, the average smartphone, which uses a wide variety of ICT, is covered by around 250,000 patents, up from 70,000 patents in 2003 (Reidenberg 2015). In addition, patents of technical standards, guidelines, or specifications that govern the interaction of technologies in products, processes, and services, grew rapidly. Technical standards are used widely in ICT technologies, including smartphones (see sidebar Technical Standards, Invention, Innovation, and Economic Growth). The growth in ICT patents over the last decade was led by digital communication (195%) and computer technology (126%).

Patents in the chemistry and health category grew slightly faster (84%) than all patents (75%) between 2006 and 2016 (Figure 8-6; Appendix Table 8-11 through Appendix Table 8-17). Medical technology patents grew the fastest among this category (140%), resulting in its share of all patents rising from 4% to 6%. Two other technologies—pharmaceuticals (Appendix Table 8-13) and basic material chemistry (Appendix Table 8-14)—also had strong growth.

Patents in the testing, measuring, and control category grew significantly slower than all patents (43%) over the last decade (Figure 8-6; Appendix Table 8-18 through Appendix Table 8-21). Within this category, patents in analysis of biological materials grew the fastest (84%), albeit from a very low base. Patents in control technology grew modestly (74%).

Patents in the materials and nanotechnology category grew slower than all patents over the last decade (Figure 8-6; Appendix Table 8-22 through Appendix Table 8-24). Patents in materials and metallurgy and in surface technology and coating had modest growth; patents in microstructural and nanotechnology grew slightly (10%).

SIDEBAR

Technical Standards, Invention, Innovation, and Economic Growth

A technical standard is "a document that provides requirements, specifications, guidelines or characteristics that can be used consistently to ensure that materials, products, processes and services are fit for their purpose."* Standards are widely used in industries and firms that produce, use, or rely on information and communications technologies. A technical standard may be developed privately or unilaterally (e.g., by a corporation or regulatory body, by groups such as trade unions and trade associations). Standards organizations often have more diverse input and usually develop voluntary standards. For example, the International Organization for Standardization (ISO) develops innovation management standards.†

One example of a technical standard is Apple's operating system for the iPhone, which governs the interface and function of the large number of iPhone applications (apps). Apple's technical standards allow many companies and developers to provide apps that increase the iPhone's utility, value, and desirability. A second example is the National Institute of Standards and Technology (NIST) ThermoData Engine Standard Reference Database. This database enables U.S. chemical companies to save valuable time and expense by using simulations rather than running full-scale experiments to design their products and assess the safety and efficiency of their manufacturing processes.

The number of standards is proliferating in the global economy, coinciding with the globalization of high-technology value chains and the complexity and pervasiveness of technologies embedded in products and services. The growth of shared platforms such as the Internet and cellular telephony has been a significant driver in the growing demand for standards. For example, the semiconductor industry is estimated to have at least 1,000 standards.

Researchers and policymakers are increasingly interested in standards because they appear to play an important role in facilitating technological development, innovation, and increasing economic growth. Several studies have found that standards are significantly associated with economic growth through greater diffusion of knowledge. However, the impact of standards on innovation and economic growth is not fully understood because of these standards' complexity and the limited amount of research in this area. Furthermore, the existing research has mostly focused on developed countries, with few studies on China and other developing countries (Ernst 2013:5). The limited amount of research suggests that standards increase industry growth and productivity, which can increase a country's economic growth. One study found the following wide-ranging impacts of standards on economic growth and innovation (Tassey 2015:189–90):

- Raising the efficiency of R&D
- Expanding existing markets and creating new markets for an industry's products and services
- Increasing the growth and productivity of incumbent firms
- Facilitating the entry of small and medium-sized firms, which can increase innovation and growth of the entire industry

The rapid growth of standards has coincided with a boom in standard essential patents (SEPs), which cover technologies that are part of standards. A company needs these patents to produce any product that meets the specifications defined in the standard when it is not possible to comply with the standard without infringing on the intellectual property protected by the SEP. A company can make a standard-compliant product by owning the SEPs or by licensing SEPs owned by others.

SEPs are considered crucial for achieving rapid, broad-based diffusion of knowledge to stimulate innovation. However, research suggests that SEPs can hinder the positive economic and social benefits of standards because of several factors, including uncertainty about whether an SEP is really essential, lack of transparency of the licensing conditions, market-distorting patenting strategies, and costly and time-consuming litigation (Ernst 2016:2–3). The growing number of SEPs increases the likelihood of "royalty stacking," where the cumulative payable royalties for SEPs exceeds a reasonable level or may even become prohibitive for implementing products (Ernst 2016:5). In addition, many technologies that are patented in standards are not considered essential.

Standards consist of two types: product and non-product. Product standards govern the performance and function of components used in high-technology products and prescribe procedures to test product development, production, and market transactions. In the United States, businesses have typically developed product standards by reaching voluntary consensus with relevant stakeholders, including firms in the industry, suppliers, and R&D laboratories.

Nonproduct standards have more general and broader functions than product standards. These standards generally govern the efficiency, operation, and performance of the entire industry. Examples include measurement and test methods, interface standards, scientific and engineering databases, and standard reference materials (Tassey 2015:192). Nonproduct standards have become increasingly important because many high-technology products are a complex mix of goods and services.

The two types of nonproduct standards are technical and basic. Technical nonproduct standards are operational, applied functions and guidelines that govern the performance, function, and interaction of services and products. U.S. industries have also developed technical nonproduct standards through a voluntary consensus approach. The second type is basic nonproduct standards, which include generic measurement and test methods that are typically derived from fundamental scientific principles, such as the laws of physics. Although these standards have wide applications in industry, firms and even industries tend to underinvest because they are expensive and require an extensive and specialized scientific infrastructure. Therefore, basic standards are considered a public good and usually have some degree of public involvement in many developed countries. NIST provides this function for the United States.

* ISO is the source of this definition (https://www.iso.org/standards.html).

† For more information on ISO's work on innovation management standards, see https://www.iso.org/committee/4587737.html.

Country-level concentration in patenting technology areas

In contrast to growth rates, patent activity indexes provide insight into the areas where each country is concentrating its patenting activity. As noted previously, many factors, including industry-level propensity to patent and patent litigation, influence patenting activity. This section presents patent activity indexes of the United States, the EU, and several Asian economies in these technologies averaged for 2014–16, based on analysis of USPTO data. The Patenting Activity Index indicates the extent to which a country's patents are concentrated in a particular technology. It is an output measure of specialization, assessing the share of a country's patents produced in each technological area. The indicator is computed by comparing a country to the global average (see sidebar Patent Data Analytics and Terminology). Technologies with an activity index of 1.2 or more are defined here as relatively more concentrated.

SIDEBAR

Patent Data Analytics and Terminology

USPTO Data

The patents referred to in analyses throughout *Science and Engineering Indicators 2018* are registered with the U.S. Patent and Trademark Office (USPTO), the federal agency responsible for handling patent and trademark applications in the United States. USPTO executes these processes for U.S. intellectual property management, coordinating more than 6,000 patent examiners and 5 patent offices across the United States, and it provides access to its data through several different portals.

PatentsView Database

PatentsView is the data source used for much of the analyses of patenting behavior presented in *Science and Engineering Indicators 2018.* It is a data analysis and visualization platform for USPTO data developed by USPTO in collaboration with other federal agencies and academic institutions. In addition to parsing, structuring, and standardizing patent data, the PatentsView initiative makes considerable efforts to disambiguate names and locations in USPTO patent data while also associating patents with their relevant technology fields based on multiple taxonomies.

Patent Technology Areas

The PatentsView database classifies patents under four different taxonomies: Cooperative Patent Classification, World Intellectual Property Organization (WIPO), U.S. Patent Classification, and National Bureau of Economic Research. For *Science and Engineering Indicators 2018*, the WIPO classification is applied, which divides patents into 35 categories based on International Patent Classification (IPC) codes. Each patent can be tagged with multiple IPC codes and can thus fall under multiple WIPO technology areas. The U.S. Patent Classification is also used to identify patents related to clean technologies.

Matching Citations to Nonpatent Literature

Patents cite other patents, showing how a novel invention builds on and distinguishes itself from other patents within the existing technological ecosystem. Some citations show the connection between inventions and a broader ecosystem, citing nonpatent literature (NPL). Matching these citations to peer-reviewed scientific publications is of interest as a means by which to assess the uptake of research in subsequent development efforts.

The matching of NPL citations from PatentsView to records in Scopus is done by an algorithm that extracts and parses publication titles; publication years; author names; and names or abbreviated names of research journals and conference proceedings, volume and issue numbers, and page ranges. These extracted data are then algorithmically compared with information extracted from the Scopus database (see sidebar Bibliometric Data and Terminology in Chapter 5) to match NPL citations in PatentsView to their cited publications appearing in Scopus.

***Patent-Related Indicators in* Indicators 2018**

Patents Granted

This indicator reflects the number of patents granted to a country, sector, or organization. Patents are attributed using the fractional counting method (see sidebar Bibliometric Data and Terminology in Chapter 5). Patents also have inventors (one or more) and grantees, where the latter become the owners of the intellectual property covered by the patent. For most scores presented in this chapter, this indicator presents the fractional count of patents by inventor, although some present information by grantee; the notes for tables and figures always specify the approach. More than 143,000 patents were granted to U.S. inventors in 2016 (Appendix Table 8-4).

Patenting Activity Index

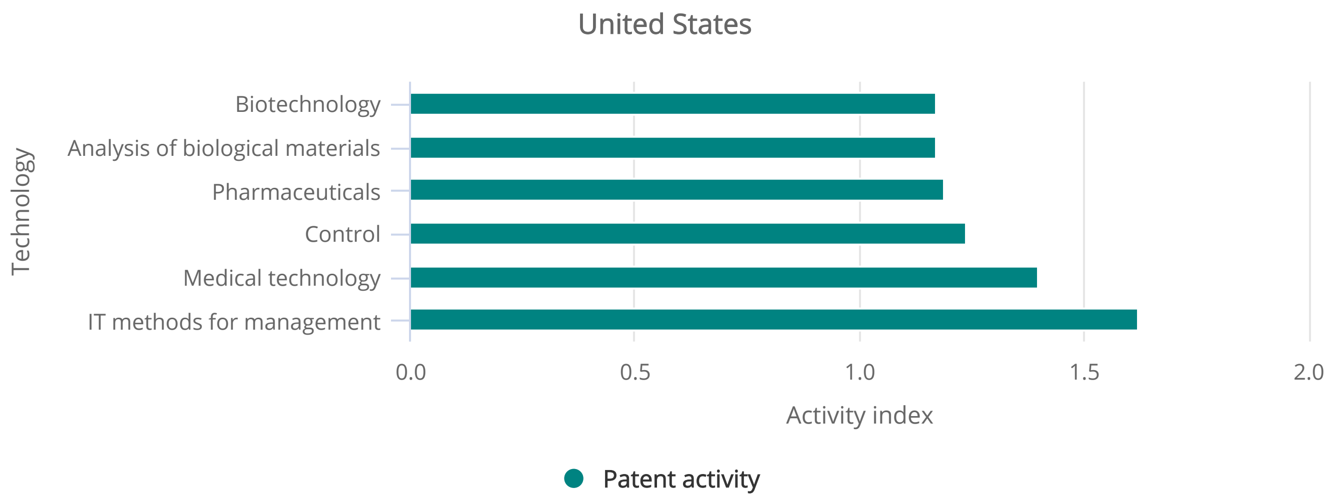
For any given area of technological development, the Patenting Activity Index indicates the extent to which a country specializes in that area. It is an output measure of specialization, assessing the share of a country's patents produced in each technological area. The indicator is computed by comparing a country to the global average. In 2016, for instance, the United States produced about 3,300 of its 143,000 patents in IT methods for management. By comparison, at the world level, only about 4,400 of 304,000 total patents were granted in IT methods for management (Appendix Table 8-4 and Appendix Table 8-10. Thus, the United States produces more patents in this area than expected, based on its total output and the world proportions.

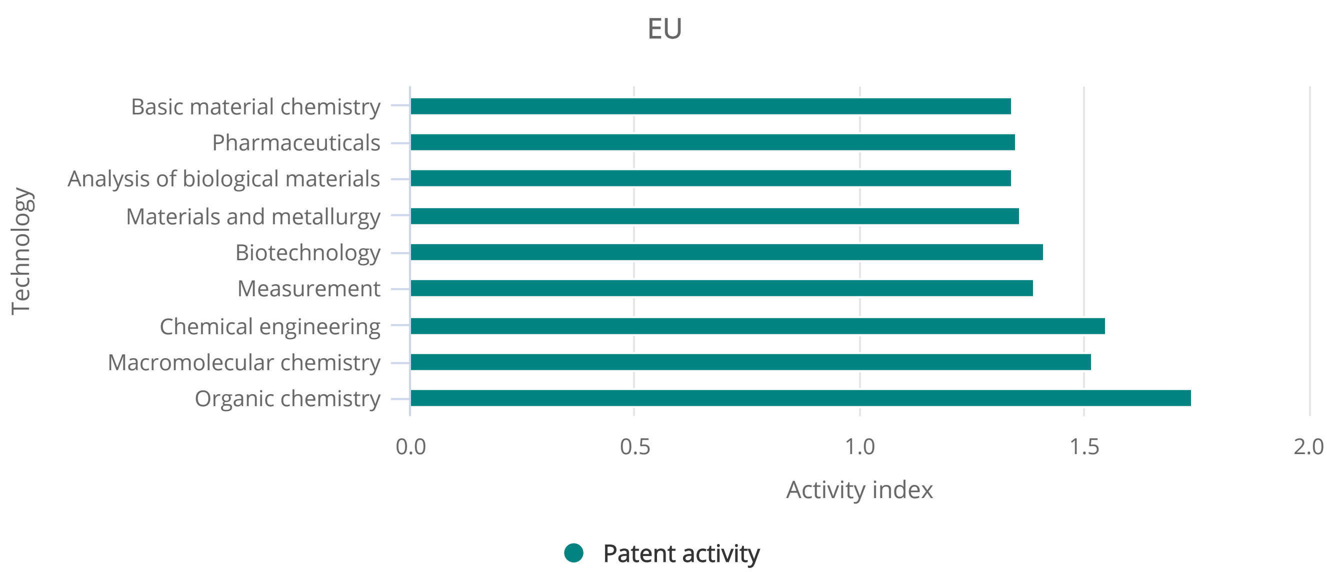
This indicator is indexed to 1.00, which represents the world level, meaning that a score above 1.00 shows that a country produces more of its patent output in the given technological area than the global proportion, whereas a score below 1.00 shows that a country produces fewer patents in this technological area than the global average. Whenever a country's share of patents in one area increases, its share in other areas must decrease proportionately.

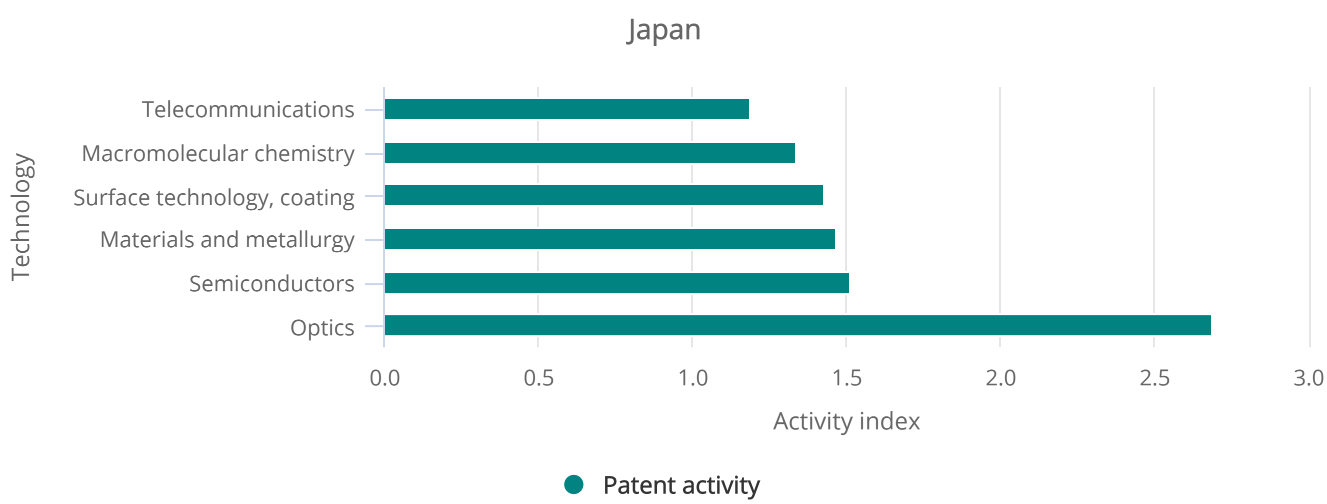
Patenting in the United States is relatively more concentrated in six technologies (Figure 8-8; Appendix Table 8-25). Three of these are in the chemistry and health category—medical technology, pharmaceuticals, and biotechnology. The United States has a high concentration in analysis of biological materials, a technology classified in the testing, measuring, and control category, that is closely related to the chemistry and health category. The concentration of U.S. patenting activities in pharmaceuticals, analysis of biological materials, and biotechnology coincides with the strong U.S. market position in and considerable R&D investment in pharmaceuticals. The U.S. concentration in medical technology and control technologies coincides with a strong market position in testing, measuring, and control instruments. U.S. patenting is concentrated in one technology in the ICT category, information technology (IT) methods for management, which consists of business methods and software methods for data processing.

FIGURE 8-8

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







EU = European Union; IT = information technology.

Note(s)

A patent activity index is the ratio of a country's share of a technology area to its share of all patents. A patent activity index greater (less) than 1.0 indicates that the country is relatively more (less) active in the technology area. Patents are classified under the World Intellectual Property Organization (WIPO) classification of patents, which classifies International Patent Classification (IPC) codes under 35 technical fields. IPC reformed codes take into account changes that were made to the WIPO classification in 2006 under the eighth version of the classification and were used to prepare these data. However, because PatentsView only provides the original IPC codes as they appeared on patents and not the IPC reformed codes, current Cooperative Patent Classification codes on patents were converted back to the most recent IPC classification to prepare these statistics. Fractional counts of patents were assigned to each technological field on patents to assign the proper weight of a patent to the corresponding technological fields under the classification. Patents are fractionally allocated among regions, countries, or economies based on the proportion of residences of all named inventors.

Source(s)

Science-Metrix; PatentsView; SRI International, accessed April 2017.

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The EU's USPTO patenting is relatively more concentrated in nine technologies, with six that are in the chemistry and health category (Table 8-2; Figure 8-8; Appendix Table 8-25). The EU has a relatively high concentration in organic chemistry (1.7) and relatively high concentrations (1.3–1.6) in six other technologies: macromolecular chemistry, chemical engineering, biotechnology, pharmaceuticals, and basic material chemistry. The relatively high concentration in pharmaceuticals and biotechnology coincides with the EU's strong market position in pharmaceuticals. In the testing, measuring, and control category, the EU is relatively more concentrated in measurement (1.4), which is consistent with the EU's relatively strong market position in testing, measuring, and control instruments. The EU is relatively less concentrated in all technologies in the ICT category.

Japan's concentration of USPTO patenting is far different from that of the United States or the EU. Japan has a very high concentration in optics (2.7), a technology in the testing, measuring, and control category, coinciding with dominance of Japanese-based companies in photography and imaging, including Canon, Fujifilm, Nikon, and Olympus (Table 8-2; Figure 8-8; Appendix Table 8-25). Japan has a moderately high concentration in two technologies in the ICT category—

semiconductors (1.5) and telecommunications (1.2)—despite its considerable loss of market share in these two industries. Japan has a relatively high concentration in two technologies in the materials and nanotechnology category—surface technology and coating (1.4) and materials and metallurgy (1.5).

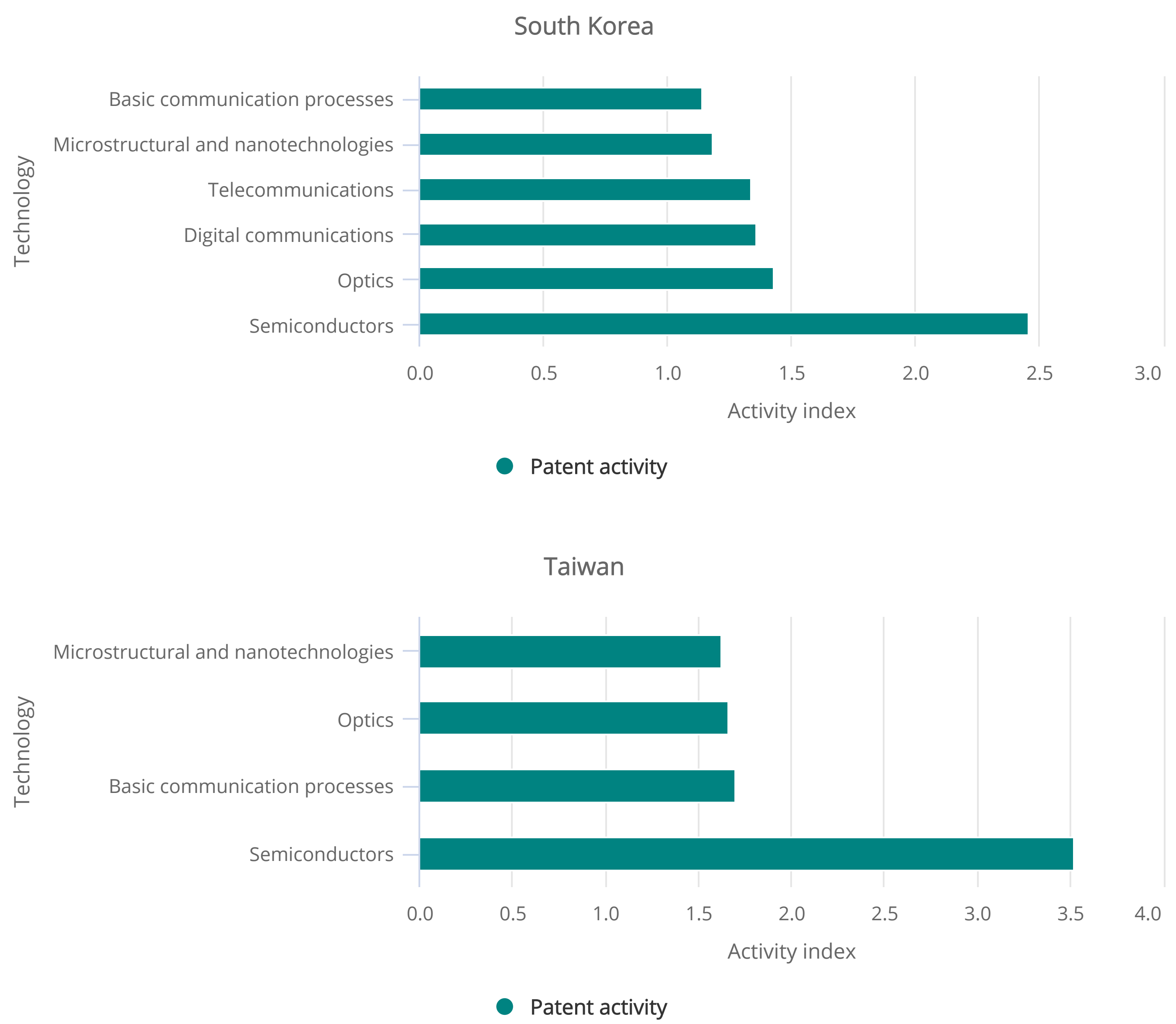
South Korea is relatively more concentrated in four technologies in the ICT category—semiconductors, digital communications, telecommunications, and basic communication processes (Table 8-2; Figure 8-9; Appendix Table 8-25). South Korea's concentration in patenting of these technologies, particularly semiconductors, coincides with its strong market position in the ICT manufacturing industries of semiconductors and communications. South Korea, like Japan, has a relatively high concentration in optics.

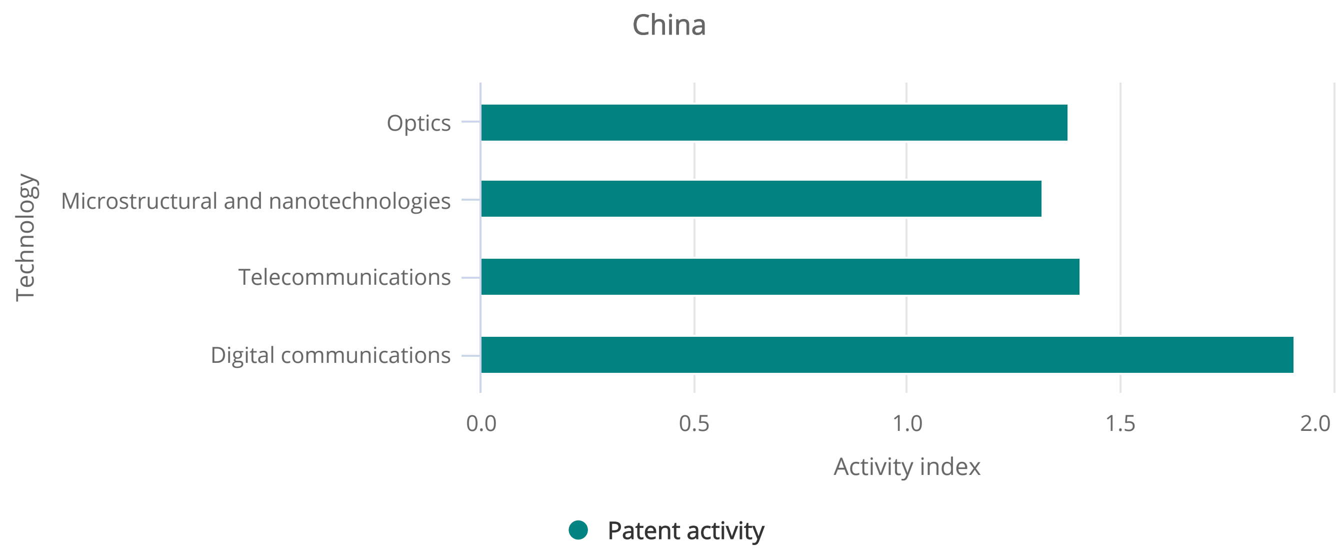
Taiwan has a high concentration in two technologies in the ICT category: semiconductors, coinciding with its very strong market position in the semiconductors industry, and basic communication processes (Figure 8-9; Appendix Table 8-25). Taiwan, like Japan and South Korea, has a relatively high concentration in optics. Taiwan has a relatively high concentration in microstructural and nanotechnologies in contrast to the relatively low concentrations of the United States, the EU, Japan, and South Korea.

China has a relatively high concentration in four technologies, including two technologies in the ICT category—telecommunications and digital communications (Table 8-2; Figure 8-9; Appendix Table 8-25). China has a lower concentration in semiconductors. This is consistent with its technological development, where its industry lags behind firms based in South Korea, Taiwan, and other countries. China, like Taiwan, has a relatively high concentration in microstructural and nanotechnologies.

FIGURE 8-9

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





Note(s)

A patent activity index is the ratio of a country's share of a technology area to its share of all patents. A patent activity index greater (less) than 1.0 indicates that the country is relatively more (less) active in the technology area. Patents are classified under the World Intellectual Property Organization (WIPO) classification of patents, which classifies International Patent Classification (IPC) codes under 35 technical fields. IPC reformed codes take into account changes that were made to the WIPO classification in 2006 under the eighth version of the classification and were used to prepare these data. However, because PatentsView only provides the original IPC codes as they appeared on patents and not the IPC reformed codes, current Cooperative Patent Classification codes on patents were converted back to the most recent IPC classification to prepare these statistics. Fractional counts of patents were assigned to each technological field on patents to assign the proper weight of a patent to the corresponding technological fields under the classification. Patents are fractionally allocated among regions, countries, or economies based on the proportion of residences of all named inventors.

Source(s)

Science-Metrix; PatentsView; SRI International, accessed December 2016.

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[1] Figure 8-1 shows 2011 data because that is the most recent year for which these data are available for R&D-performing firms as well as firms that do not perform R&D. For R&D-performing firms, these data are available from NSF's 2015 BRDIS.

Knowledge Transfer

Scientific discoveries and inventions flow into economic activity through market-based and freely provided activities. Flows of both types can occur through person-to-person exchange or through access to formal or codified knowledge. *Technology transfer* is "the process by which technology or knowledge developed in one place or for one purpose is applied and used in another place for the same or different purpose" (Federal Laboratory Consortium for Technology Transfer [FLC] 2013:3). Academic, government, business, and nonprofit organizations have policies and programs to help bring knowledge and technology into hands of those with abilities to apply, further develop, and eventually commercialize their research. For example, technology management and transfer offices support patenting or otherwise protected research produced in their institutions' laboratories to enable potential use through licensing by others or as the basis for a startup firm. Federal agencies and their laboratories, as well as U.S. academic research institutions, have established technology management and transfer offices to support the transmission of their research.

This section begins with a presentation of technology transfer metrics for universities and for federal agencies and their laboratories. These metrics include invention disclosures, patents, and licensing. For academic institutions, data on royalties and startup formation are presented. For federal agencies and their laboratories, cooperative R&D agreement counts are also presented. Next, coauthorship counts of peer-reviewed S&E literature and citations of S&E articles in patents provide indicators of the flow of knowledge from S&E literature to potentially commercializable inventions. The knowledge transfer section ends with the discussion and presentation of international transaction data on licensing and royalties, a market-based measure of trade in knowledge products and intellectual property.

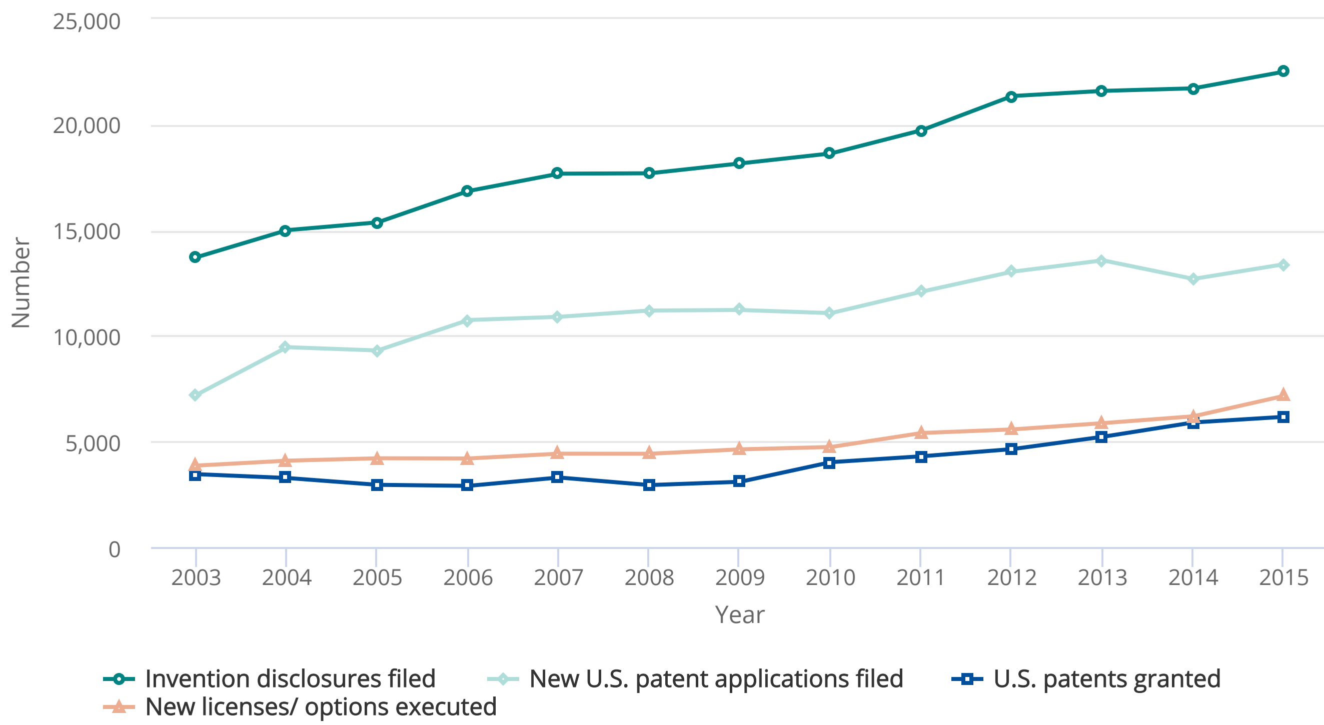
Knowledge Transfer Activities by Academic Institutions

Collaborative R&D activities among universities and colleges, businesses, and other parties have taken place in the United States throughout the 20th and early 21st century. And as federal funding of academic research expanded in the post–World War II era, academic administrations became increasingly engaged in patent management (Mowery et al. 2004). The Bayh–Dole Act (Patent and Trademark Act Amendments of 1980, P.L. 96–517) created a uniform patent policy among the many federal agencies that fund research, enabling small businesses and nonprofit organizations, including universities, to retain ownership of inventions made under federally funded research programs. The Bayh-Dole Act has since been engaged by large companies as well. It is widely regarded as having been an important stimulant since its 1980 enactment for academic institutions to pursue technology transfer activities. Other countries implemented policies like the Bayh–Dole Act by the early 2000s, giving their academic institutions (rather than inventors or the government) ownership of patents resulting from government-funded research (Geuna and Rossi 2011).

The Association of University Technology Managers (AUTM) gathers information on the invention and main patent-related activities of its member universities. Invention disclosures filed with university technology management and transfer offices describe prospective inventions and are submitted before a patent application is filed. The number of these disclosures grew from 13,718 in 2003 to 22,507 in 2015 (notwithstanding small shifts in the number of institutions responding to the AUTM survey over the same period) (Figure 8-10). Likewise, new U.S. patent applications filed by AUTM university respondents also increased, nearly doubling from 7,203 in 2003 to 13,389 in 2015. As described earlier for all U.S. academic patents, U.S. patents awarded to AUTM respondents stayed flat between 2003 and 2009, before rising to reach 6,164 in 2015 (see Appendix Table 8-26).

FIGURE 8-10

U.S. university patenting activities: 2003–15



Source(s)

Association of University Technology Managers (AUTM), AUTM Licensing Surveys: 2003–15. See Appendix Table 8-26.

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Data from AUTM also provide counts of new startups formed and of startups still operating, and these indicators also show an increased growth rate since 2009. New startups reached 950 in 2015 with the number of past startups still operating 4,757 in 2015 (Appendix Table 8-26). Active licenses increased from 18,845 in 2001 to 40,402 in 2015.

While license income is not the dominant objective of university technology management offices (Thursby, Jensen, and Thursby 2001), the 165 institutions that responded to the AUTM survey reported a total of $1.8 billion in net royalties from their patent holdings in 2015. This amount has grown from $754 million in 2001 (Appendix Table 8-26).

Knowledge Transfer Activities by Federal R&D Facilities

The Stevenson-Wydler Technology and Innovation Act of 1980 (P.L. 96–480) directed federal agencies with laboratory operations to become active in the technology transfer process. It also required these agencies to establish technology transfer offices (termed Offices of Research and Technology Applications) to assist in identifying transfer opportunities and establishing appropriate arrangements for transfer relationships with nonfederal parties. Follow-on legislation in the 1980s and through 2000 amending the Stevenson-Wydler Act has worked to extend and refine the authorities available to the agencies and their federal laboratories to identify and manage intellectual assets created by their R&D and to participate in collaborative R&D relationships with nonfederal parties, including private businesses, universities, and nonprofit organizations (FLC 2013).

As indicated in Chapter 4, about 11% of the current U.S. R&D total ($54.3 billion of $495.1 billion in 2015; see Table 4-1 in Chapter 4) is performed by the federal government, through federal agencies' own research facilities and the 41 federally funded research and development centers (FFRDCs). In response to these longstanding federal policies promoting technology transfer, nearly all the agencies and their associated federal laboratories have become active in recognizing and promoting the transfer of inventions from their own R&D with potential for commercial applications.

As applied in the federal setting, technology transfer can occur through varied channels: *commercial transfer* (the movement of knowledge or technology developed by a federal laboratory to private organizations or the commercial marketplace), *scientific dissemination* (publications, conference papers, and working papers distributed through scientific or technical channels, or other forms of data dissemination), *export of resources* (federal laboratory personnel made available to outside organizations with R&D needs, through collaborative agreements or other service mechanisms), *import of resources* (outside technology or expertise brought in by a federal laboratory to enhance existing internal capabilities), and *dual use* (development of technologies, products, or families of products with commercial and federal [mainly military] applications).

The metrics on federal technology transfer continue to primarily track the number of activities—that is, invention disclosures, patent applications and awards, licenses to outside parties of patents and other intellectual property, and agreements to conduct collaborative research with outside parties (Institute for Defense Analyses, Science and Technology Policy Institute 2011). Nonetheless, systematic documentation of the downstream outcomes and impacts of transfer remains a challenge.[1] Also missing (until most recently) for most agencies and their laboratories are comprehensive data on technology transfer through the *scientific dissemination* mode (i.e., technical articles published in professional journals, conference papers, and other kinds of scientific communications), which remains widely regarded by laboratory scientists, engineers, and managers (federal and private sector) as a key means of transfer. The Department of Commerce's (DOC's) most recent *Summary Report* on federal laboratory technology transfer (with data on FY 2014, published October 2016) is expanded to include a bibliometric analysis of scientific/technical publications originating from federal laboratories (DOC/National Institute of Standards and Technology [NIST] 2016). Additional perspective on this topic is provided earlier in Table 5-25 in Chapter 5, where an original bibliometric analysis conducted for *Science and Engineering Indicators* contrasts the share of U.S. S&E articles in 2016 for the federal government with that for other performers.

Seven agencies account for most of the annual total of federal technology transfer activities: Department of Defense (DOD), Department of Health and Human Services (HHS), Department of Energy (DOE), National Aeronautics and Space Administration (NASA), U.S. Department of Agriculture (USDA), DOC, and Department of Homeland Security (DHS). (Each of these agencies also conducts more than $1 billion of R&D annually through its intramural facilities or FFRDCs; see Table 4-16 in Chapter 4.) Technology transfer statistics for these agencies for FY 2014 (the latest data year available), with comparisons with FYs 2006, 2009, and 2012, appear in Table 8-3. (Similar statistics for a larger set of agencies, going back to FY 2001, appear in Appendix Table 8-27.) Consistent with the agencies' statutory annual reports, these statistics mainly cover the activity areas of invention disclosures and patenting, intellectual property licensing, and collaborative relationships for R&D.

TABLE 8-3

Federal laboratory technology transfer activity indicators, by selected agencies: FYs 2006, 2009, 2012, 2014

(Number of activities)

Fiscal year	Technology transfer activity	All federal laboratories	DOD	HHS	DOE	NASA	USDA	DOC	DHS
2014	Invention disclosures and patenting								
	Inventions disclosed	5,103	963	351	1,588	1,683	117	47	36
	Patent applications	2,609	916	216	1,144	146	119	25	5
	Patents issued	1,931	670	335	693	117	83	18	3
	Licensing								
	All licenses, total active in the fiscal year	20,822	527	1,555	5,861	2,381	414	41	10,313
	Invention licenses	3,956	425	1,186	1,560	253	363	41	2
	Other intellectual property licenses	16,866	102	369	4,301	2,128	51	0	10,311
	Collaborative relationships for R&D								
	CRADAs, total active in the fiscal year	9,180	2,762	532	704	0	267	2,359	158
	Traditional CRADAs	4,891	2,281	378	704	0	193	206	121
	Other collaborative R&D relationships	27,182	581	154	0	6,058	17,005	3,031	31
2012	Invention disclosures and patenting								
	Inventions disclosed	5,350	1,078	352	1,661	1,642	160	52	40
	Patent applications	2,361	1,013	233	780	131	122	21	10
	Patents issued	2,228	1,048	453	483	129	69	3	0
	Licensing								
	All licenses, total active in the fiscal year	11,452	520	1,465	5,328	3,013	384	41	523
	Invention licenses	3,882	432	1,090	1,428	284	341	41	0
	Other intellectual property licenses	7,660	88	375	3,900	2,729	43	0	523
	Collaborative relationships for R&D								
	CRADAs, total active in the fiscal year	8,307	2,400	377	742	0	274	2,410	94
	Traditional CRADAs	4,292	1,328	245	742	0	211	153	89

Fiscal year	Technology transfer activity	All federal laboratories	DOD	HHS	DOE	NASA	USDA	DOC	DHS
	Other collaborative R&D relationships	24,717	0	0	0	5,749	15,878	2,782	11
2009	Invention disclosures and patenting								
	Inventions disclosed	4,452	831	389	1,439	1,412	143	41	32
	Patent applications	1,957	690	156	775	141	123	20	2
	Patents issued	1,319	404	397	363	93	24	7	2
	Licensing								
	All licenses, total active in the fiscal year	12,598	432	1,584	5,742	4,181	330	40	63
	Invention licenses	3,854	386	1,304	1,452	146	302	40	45
	Other intellectual property licenses	8,744	46	280	4,290	4,035	28	0	18
	Collaborative relationships for R&D								
	CRADAs, total active in the fiscal year	7,756	2,870	457	744	1	259	2,397	23
	Traditional CRADAs	4,296	2,247	284	744	1	207	101	22
	Other collaborative R&D relationships	17,649	1	0	0	4,507	10,306	2,828	5
2006	Invention disclosures and patenting								
	Inventions disclosed	5,193	1,056	442	1,694	1,749	105	14	NA
	Patent applications	1,912	691	166	726	142	83	5	NA
	Patents issued	1,284	472	164	438	85	39	7	NA
	Licensing								
	All licenses, total active in the fiscal year	10,186	444	1,535	5,916	2,856	332	111	NA
	Invention licenses	4,163	438	1,213	1,420	308	332	111	NA
	Other intellectual property licenses	6,023	6	322	4,496	2,548	0	0	NA
	Collaborative relationships for R&D								
	CRADAs, total active in the fiscal year	7,268	2,999	164	631	1	195	3,008	NA
	Traditional CRADAs	3,666	2,424	92	631	1	163	149	NA
	Other collaborative R&D relationships	9,738	0	0	0	4,275	3,477	2,114	NA

NA = not available.

CRADA = Cooperative R&D Agreement; DHS = Department of Homeland Security; DOC = Department of Commerce; DOD = Department of Defense; DOE = Department of Energy; HHS = Department of Health and Human Services; NASA = National Aeronautics and Space Administration; USDA = Department of Agriculture.

Note(s)

The table includes seven federal departments and agencies that reported R&D obligations at or above $1 billion in FY 2014. (The National Science Foundation was also in this group, but its corresponding data were not available.) Other federal agencies not listed but included in the All federal laboratories totals are the Department of the Interior, Department of Transportation, Department of Veterans Affairs, and Environmental Protection Agency. Invention licenses refer to inventions that are patented or could be patented. Other intellectual property refers to intellectual property protected through mechanisms other than a patent (e.g., copyright). CRADAs refers to all agreements executed under CRADA authority (15 U.S.C. 3710a). Traditional CRADAs are collaborative R&D partnerships between a federal laboratory and one or more nonfederal organizations. Federal agencies have varying authorities for other kinds of collaborative R&D relationships.

Source(s)

National Institute of Standards and Technology, U.S. Department of Commerce, *Federal Laboratory Technology Transfer, Fiscal Year 2014: Summary Report to the President and the Congress* (2016), https://www.nist.gov/sites/default/files/documents/2016/10/26/fy2014_federal_tech_transfer_report.pdf. See Appendix Table 4-30.

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As the distribution of the statistics across the activity types in Table 8-3 shows, most of these agencies engage in all the transfer activity types to some degree—although the emphases differ. Some agencies (e.g., DOD, DOE, HHS) are particularly intensive in patenting and licensing activities; others (e.g., DOC, NASA, USDA) are intensive on transfer through collaborative R&D relationships. Furthermore, some agencies have unique transfer authorities (statutory) that can confer practical advantages. NASA, for example, can establish collaborative R&D relationships through special authorities it has under the National Aeronautics and Space Act of 1958; USDA has several special authorities for establishing R&D collaborations other than cooperative research and development agreements; DOE has contractor-operated national laboratories, with nonfederal staff, that are not constrained by the normal federal limitation on copyright by federal employees and can use copyright to protect and transfer computer software. In general, the mix of technology transfer activities pursued by each agency reflects a broad range of considerations such as agency mission priorities, the technologies principally targeted for development, the intellectual property protection tools and policies available, and the types of external parties through which transfer and collaboration are chiefly pursued.

The data for the most recent years in this series (FYs 2012–14) indicate that federal agency laboratories and FFRDCs as a group put forth some 5,100–5,400 invention disclosures annually, 2,400–2,600 patent applications, and receive 1,900–2,200 patent awards. These numbers have generally grown over the years, which is more apparent in the longer time series of data available in Appendix Table 8-27.

Year to year, the intramural or FFRDC laboratories of DOE and DOD consistently account for the largest levels of invention disclosures, patent applications, and patent awards. For example, DOE reported 1,588 invention disclosures in FY 2014, 1,144 patent applications, and 693 patent awards; DOD reported 963 invention disclosures, 916 patent applications, and 670 patent awards (Table 8-4). In contrast, HHS, which is also one of the largest intramural or FFRDC R&D performers, reported 351 invention disclosures in FY 2014, 216 patent applications, and 335 patent awards. Further, NASA reported a high number of invention disclosures in FY 2014 but had low levels of patent applications and awards (146 and 117, respectively). This emphasizes that care must be used in comparing the track of these invention indicators over time and across agencies. Depending on the technologies involved, application areas, type of external development partners, and technology transfer authorities available—all of which vary across the federal government—the priority of attention to patenting as a main mechanism for promoting the transfer and downstream commercial development of federal laboratory inventions can differ among the agencies.

TABLE 8-4

Invention disclosures and patenting, by selected U.S. agencies with federal laboratories: FYs 2006–14

(Number)

Invention disclosures and patenting	2006	2007	2008	2009	2010	2011	2012	2013	2014
All 11 agencies[a]									
Inventions disclosed	5,193	4,486	4,572	4,452	4,755	5,251	5,350	5,321	5,103
Patent applications filed	1,912	1,825	1,952	1,957	2,002	2,308	2,361	2,494	2,609
Patents issued	1,284	1,405	1,253	1,319	1,468	1,449	2,228	1,855	1,931
DOD									
Inventions disclosed	1,056	838	1,018	831	698	929	1,078	1,032	963
Patent applications filed	691	597	590	690	436	844	1,013	942	916
Patents issued	472	425	462	404	304	523	1,048	648	670
HHS									
Inventions disclosed	442	447	437	389	337	351	352	320	351
Patent applications filed	166	261	164	156	291	272	233	230	216
Patents issued	164	379	278	397	470	270	453	428	335
DOE									
Inventions disclosed	1,694	1,575	1,460	1,439	1,616	1,820	1,661	1,796	1,588
Patent applications filed	726	693	904	775	965	868	780	944	1,144
Patents issued	438	441	370	363	480	460	483	554	693
NASA									
Inventions disclosed	1,749	1,514	1,324	1,412	1,735	1,723	1,642	1,618	1,683
Patent applications filed	142	127	122	141	150	130	131	146	146
Patents issued	85	68	90	93	130	111	129	116	117
USDA									
Inventions disclosed	105	126	100	143	149	158	160	191	117
Patent applications filed	83	114	123	123	113	124	122	157	119
Patents issued	39	37	30	24	45	49	69	65	83

Invention disclosures and patenting	2006	2007	2008	2009	2010	2011	2012	2013	2014
DHS									
Inventions disclosed	NA	NA	10	32	7	38	40	20	36
Patent applications filed	NA	NA	0	2	2	12	10	4	5
Patents issued	NA	NA	1	2	1	0	0	4	3
DOC									
Inventions disclosed	14	32	40	41	31	26	52	41	47
Patent applications filed	5	8	21	20	20	17	21	26	25
Patents issued	7	3	3	7	12	16	13	16	18

NA = not available.

DHS = Department of Homeland Security; DOC = Department of Commerce; DOD = Department of Defense; DOE = Department of Energy; HHS = Department of Health and Human Services; NASA = National Aeronautics and Space Administration; USDA = Department of Agriculture.

[a] Includes the 11 federal departments and agencies that report annual statistics on the technology transfer activities of their federal laboratories (statutory under the Technology Transfer Commercialization Act of 2000). In addition to the 7 departments and agencies separately described above, the totals include the activities of the Environmental Protection Agency, Department of the Interior, Department of Transportation, and Department of Veterans Affairs.

Note(s)

The 7 departments and agencies tallied above each obligated $1.0 billion or more for intramural and affiliated federally funded research and development center R&D in FY 2014 (DOD, $22.2 billion; DOE, $8.6 billion; HHS, $7.3 billion; NASA, $3.2 billion; USDA, $1.5 billion; DHS, $1.4 billion; DOC, $1.1 billion). Data for earlier years and the full set of 11 departments and agencies are in Appendix Table 4-30.

Source(s)

National Institute of Standards and Technology, U.S. Department of Commerce, *Federal Laboratory Technology Transfer, Fiscal Year 2014: Summary Report to the President and the Congress* (2016), https://www.nist.gov/sites/default/files/documents/2016/10/26/fy2014_federal_tech_transfer_report.pdf.

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Sources of Economically Valuable Knowledge

Indicators of economically valuable knowledge reflect only a portion of the knowledge about S&T that is shared. Tacit knowledge, shared through person-to-person exchanges, spreads locally and across networks of people interested in similar topics. This can take place informally and in conferences, through paid consulting and other business services, and through institutions organized for sharing knowledge and technology.

Economically valuable knowledge also spreads through publicly and freely available records, such as scientific publications, patent records, and open-source software, as well as through use of intellectual property, such as licensing of patents, copyrights, software, and trade secrets. Such documents and records are codified, or in some way formalized for transmission between people.

A key feature of knowledge is that many can use it, and it can be used repeatedly without being exhausted. It can spread or spill over to users outside the institutions where the knowledge is created. The ability for knowledge to be reused and shared across users yields great potency in fueling further economic growth (Romer 1986, 1990; Lucas 1988).

Sources of knowledge used in invention and innovation include business R&D, university and nonprofit institution research, the work of federal laboratories, and the experiences of scientists, engineers, and inventors as they create and develop new and useful products and processes. For business product innovation in manufacturing, sources outside of internal R&D labs are pervasive. Arora, Cohen, and Walsh (2016) found that for U.S. manufacturing firms, 49% reported that the invention underlying their most important innovation was external to the firm (see sidebar Open Innovation).

SIDEBAR

Open Innovation

The "open" model of innovation (Chesbrough 2003) highlights activities of firms that find it less costly to acquire their inventions from outside sources than to generate them using their own internal research and development laboratories. These firms innovate and compete successfully by sourcing technological and innovative knowledge broadly. Firm survey evidence shows the importance of the invention sources of product innovation in manufacturing that are separate from internal R&D work. For about half of the respondents to American Competitiveness Survey (ACS), which surveyed manufacturing firms with product innovations, the invention underlying their most important innovation was external to the firm. The customer was the most frequent source, followed by suppliers, and then outside technology specialists. These technology specialists include contract R&D performers, independent inventors, and universities. The ACS also finds an important role for startups as the source of invention, with 13% of respondents identifying this source (Arora, Cohen, and Walsh 2016).

One explanation for the growth in external sources of innovation is that information and communications technologies (ICT) improvements allow external innovators to create complementary products, extending the reach of open innovation (Evans and Gawer 2016). These improvements include gains in instrumentation and computing power which increase the potential for innovation to be separated into subprocesses that different teams can accomplish. By diminishing the limitations posed by geographic barriers, digital platforms allow for exchanges between suppliers and customers and for the development of new products and services. Further, ICT can raise the value of external expertise in abstract knowledge, which can be applied broadly across many fields (Arora and Gambardella 1994).

Coauthorship of Peer-Reviewed Research with the Business Sector

Coauthorship provides a means by which economically valuable knowledge can flow through collaboration with other scientists and engineers to the business sector, leading to the development of new and improved products and processes. Although the great majority of peer-reviewed S&E publications are produced by universities (described in the Chapter 5 section Publication Output, by U.S. Sector), authors with business-sector affiliations produced more than 51,000 publications in 2016 (Table 8-5), over 80% of which were coauthored with academic, government, or foreign researchers. Reflecting the importance of collaboration with academic researchers, almost half (49%) of all business publications were produced with authors from U.S. academic institutions. Government coauthors appear on 13% of all business publications, and foreign coauthors appear on more than a third of all business publications (35%).

TABLE 8-5

U.S. business-sector publications with other U.S. sectors and foreign institutions: 2016

(Number and percent)

Business-sector publications	Number	Percent
All publications	50,889	100.0
Total coauthored	41,485	81.5
Total coauthored with another U.S. sector (excluding business sector) and/ or foreign institution	37,268	73.2
Coauthored with another institution from business sector	8,408	16.5
Coauthored with another U.S. sector	28,321	55.7
Coauthored with academic sector	24,964	49.1
Coauthored with non-academic sector	9,857	19.4
Coauthored with government	6,587	12.9
Coauthored with private nonprofits and other	4,059	8.0
Coauthored with foreign institution	17,775	34.9

Note(s)

Article counts are from a selection of journals, books, and conference proceedings in S&E from Scopus. Articles are classified by their year of publication and are assigned to a sector on the basis of the institutional address(es) listed in the article. Articles are credited on a whole-count basis (i.e., each collaborating institution type is credited one count in each qualifying group). The sum of articles coauthored with various sectors could exceed the total number of articles coauthored with another sector and/or foreign sector due to articles coauthored by multiple sectors. Articles from unknown U.S. sectors are not shown. Counts of publications coauthored with another U.S. sector are limited to copublications involving the U.S. sector at stake and another different sector. For instance, the number of coauthored publications with a non-academic sector does not include publications coauthored with another institution from the U.S. business sector.

Source(s)

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

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Citations of S&E Articles and USPTO Patents

In addition to co-authorships, citations of S&E articles in patent documents provide indicators of economically-valuable knowledge as inputs to invention. Patent documents accessed from USPTO provide text citations to earlier patents issued (prior art) and to nonpatent literature (NPL), which includes peer-reviewed research and other published documents.

As an indicator of knowledge transfer, the linkages can be indirect. Earlier patents may be cited by the inventor to demonstrate their difference from prior art or added by the examiner to limit the scope of the patent (IEEE 2010). Citations to

NPL are considered stronger indicators of the impact of academic research on business patenting than citations to patents, though both miss flows from private and contract research, as well as flows from basic research (Roach and Cohen 2012).

Almost a quarter (23%) of USPTO patents issued in 2016 cite S&E articles (Table 8-6), with almost 300,000 S&E articles cited. Six fields of science accounted for nearly all (98%) of the citations in USPTO patents granted in 2016 (Appendix Table 8-28). Biological sciences make up the largest share (34%), followed by medical sciences (24%), computer sciences (12%), engineering (11%), chemistry (9%), and physics (8%) (Figure 8-11).

TABLE 8-6

U.S. utility patents citing S&E literature, by patent assignee sector, article author sector, and patent issue year: 2013–16

(Number)

Patent assignee sector and article author sector	2013	2014	2015	2016
USPTO utility patents				
All utility patents	278,517	301,643	299,382	304,126
Patents citing S&E literature, all assignee sectors	64,572	70,124	68,761	69,025
Foreign	24,641	26,902	26,664	26,941
Unknown country	92	93	91	107
United States	39,839	43,129	42,006	41,977
Government	716	751	719	695
Private	33,354	36,161	35,004	34,688
Academic	4,334	4,700	4,844	5,176
Other	324	326	337	301
Individuals	1,106	1,149	1,035	1,073
No information on organization or unclassified	7	42	67	44
S&E articles				
All S&E articles, all article author sectors	14,210,554	15,085,104	16,048,163	17,069,262
All cited S&E articles, all article author sectors	274,312	290,951	288,922	290,433
Foreign	150,246	160,215	161,203	163,365
Unknown country	1,469	1,477	1,313	1,259
United States	122,597	129,259	126,407	125,809
Federal government	5,979	6,138	6,001	5,849
Industry	20,385	21,103	19,890	18,919
Academic	81,736	86,965	85,996	86,797
FFRDCs	2,425	2,651	2,580	2,637
Nonprofit	6,635	6,843	6,782	6,510
State and local government	153	138	137	165

Patent assignee sector and article author sector	2013	2014	2015	2016
Joint or unknown sectors	5,285	5,421	5,020	4,932
Citations from USPTO utility patents to S&E articles				
All citations, all article author sectors	582,179	640,922	633,407	615,028
Foreign	301,659	336,684	337,309	329,291
Unknown country	3,098	3,232	2,913	2,744
United States	277,423	301,006	293,185	282,993
Federal government	11,738	12,428	12,114	11,396
Industry	51,465	56,946	52,842	49,392
Academic	181,090	195,796	193,748	189,995
FFRDCs	5,476	6,011	5,644	5,562
Nonprofit	14,893	16,213	16,367	15,195
State and local government	296	309	269	333
Joint or unknown sectors	12,466	13,304	12,199	11,119

FFRDC = federally funded research and development center; USPTO = U.S. Patent and Trademark Office.

Note(s)

Article and citation counts are from the set of journals covered by Scopus. Articles are assigned to a sector on the basis of the institutional address(es) listed in the article. Articles and citations are credited on a fractional-count basis (i.e., for articles with collaborating institutions from multiple sectors, each sector receives fractional credit on the basis of the proportion of its participating institutions). Citation counts are based on an 11-year window with a 5-year lag (e.g., citations for 2012 are references in U.S. patents issued in 2012 to articles published in 1997–2007). Article counts are a sum of articles in the cited-year window. Detail may not add to total because of rounding. Data in the table are not comparable to previous versions due to changes in the cited-year window.

Source(s)

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

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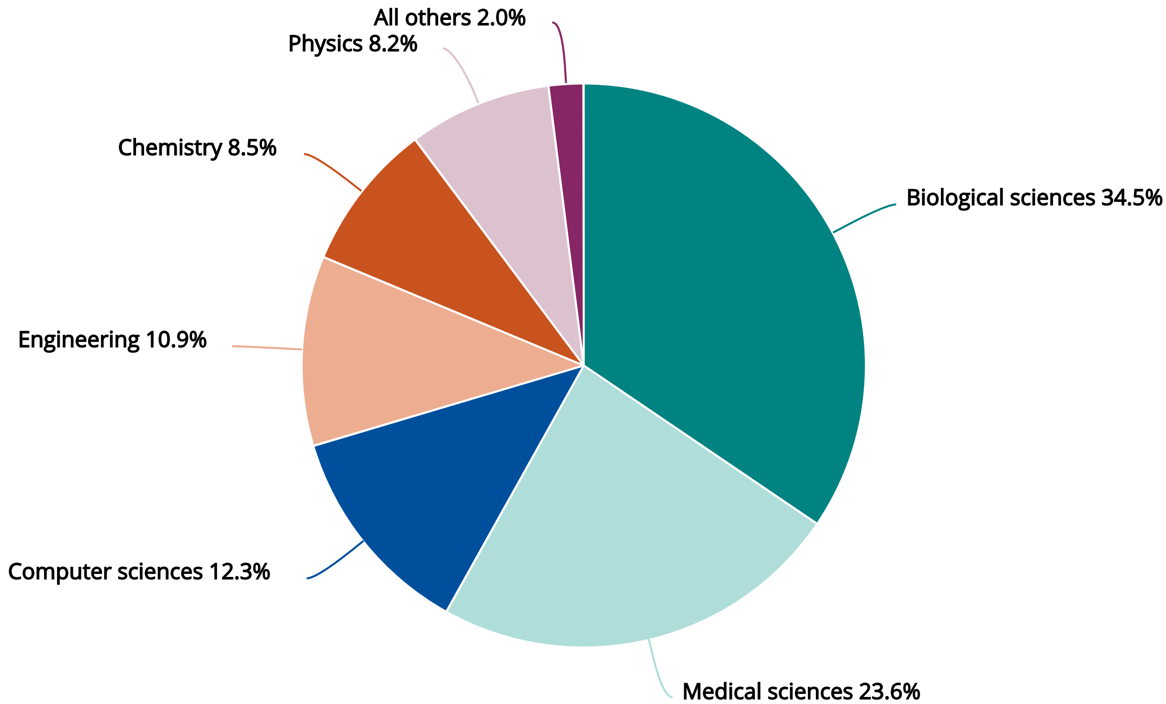
FIGURE 8-11

Citations of U.S. S&E articles in U.S. patents, by selected S&E article field: 2016



Source(s)

National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; PatentsView; U.S. Patent and Trademark Office patent data; Elsevier, Scopus abstract and citation database (https://www.scopus.com/), accessed April 2017 (patent data) and July 2017. See Appendix Table 8-28.

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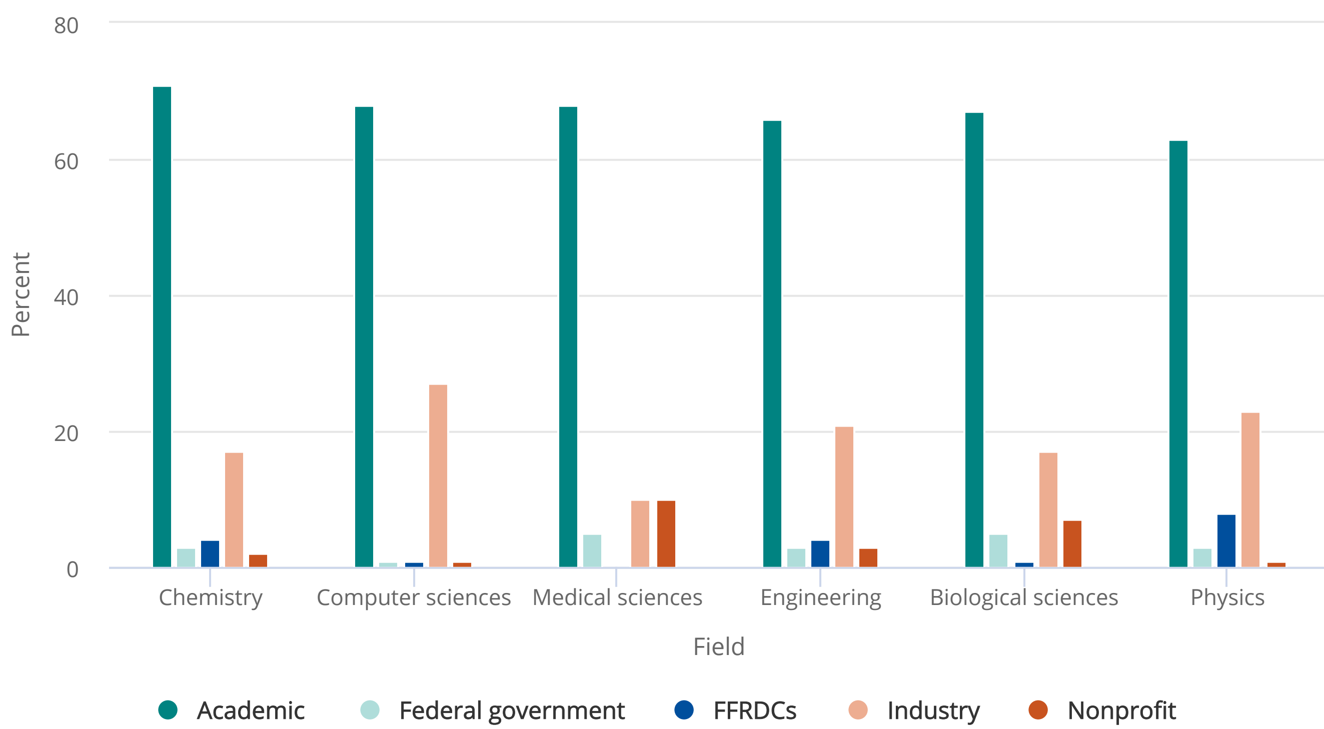
Across fields, the authors of most cited S&E literature in patent documents are from the academic sector. Consistent with its large share of S&E publications and citations overall, the U.S. academic sector received 31% of NPL citations from all USPTO patents in 2016 and 67% of citations from patents granted to U.S. patent owners. Within fields of science, industry publications receive 20% or more of the patent citations in computer sciences, engineering, and physics (Figure 8-12). Articles from other nonacademic sectors receive far fewer citations in patents, but this varies by field. After academia, industry articles capture the next largest share of citations overall, with particularly high citations in computer sciences (27%), physics (23%), and engineering (21%). In medical sciences, industry and nonprofit articles each account for 10% of patent citations. Compared with other fields, federal government S&E articles receive the largest number of citations in biological and medical sciences (each 5%), and FFRDCs receive the largest number of citations in physics (8%).

FIGURE 8-12

Citation of U.S. S&E articles in USPTO patents, by selected S&E field and article author sector: 2016



FFRDC = federally funded research and development center.

Note(s)

Fields with less than 5% in 2016 are omitted. Citations where the sector is unknown sectors are not shown. Citations to state and local government S&E articles are also not shown.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; PatentsView; U.S. Patent and Trademark Office patent data; Elsevier, Scopus abstract and citation database (https://www.scopus.com/), accessed April 2017 (patent data) and July 2017 (S&E articles data). See Appendix Table 8-28.

Science and Engineering Indicators 2018

The globalization of USPTO patents is reflected in the foreign sources of cited articles and in the foreign share of USPTO patents described earlier, in the section USPTO Patenting Activity. In 2016 foreign articles drew more citations in USPTO patents (54%) than U.S. articles (46%) (Table 8-6).

Global Flows of Payments for Intellectual Property: Trade in Licensing and Fees

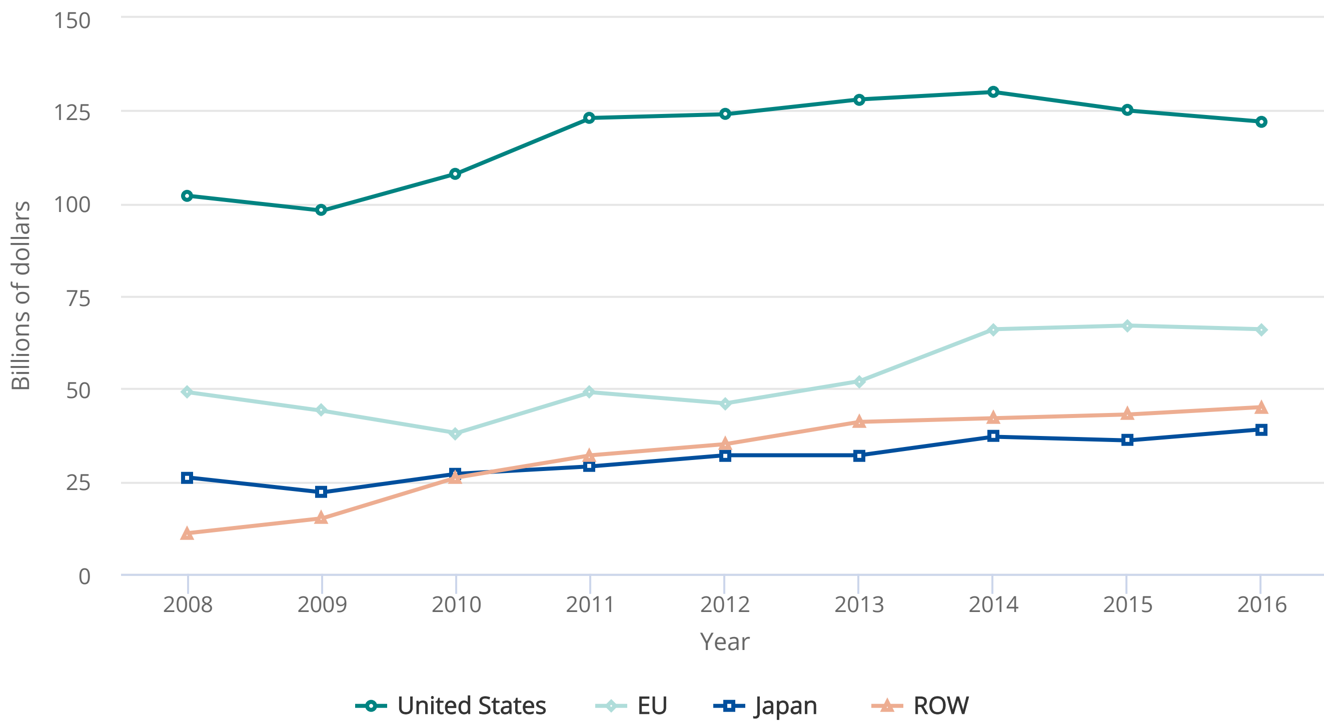
Licensing allows intellectual property developed within firms to be used externally and globally active businesses transfer their intellectual property across national boundaries, exploiting opportunities in external markets. This intellectual property includes the use of proprietary rights—patents, trademarks, copyrights, industrial processes, and designs—and licenses to reproduce and/or distribute intellectual property embodied in produced originals, prototypes, live performances, and televised broadcasts (World Trade Organization 2016).

The export revenues for these types of transactions, known as "charges for the use of intellectual property," provide a broad indicator of technology flows across the global economy and the value of an economy's intellectual property in the international marketplace.[2] Receipts from other countries for this trade provide a partial measure of market-based income for the use of intellectual property. International receipts for the use of intellectual property also represent global exports of services, playing an important role in understanding the global balance of trade. However, such receipts are a partial indicator of these flows. The volume and geographic patterns of U.S. trade in royalties and fees have been influenced by U.S.-based multinational companies transferring their intellectual property to low-tax jurisdictions or their foreign subsidiaries to reduce their U.S. and foreign taxes (Gravelle 2010:8; Mutti and Grubert 2007:112).

Global exports (receipts for the use of intellectual property) were $272 billion in 2016 (Appendix Table 8-29). The United States was the world's largest exporter (45% global share) with a substantial trade surplus (Figure 8-13).[3] However, over several years the U.S. global share has fallen from 54% in 2008 to 45% in 2016.

FIGURE 8-13

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



EU = European Union.

Note(s)

EU exports do not include intra-EU exports.

Source(s)

World Trade Organization, Trade and tariff data, https://www.wto.org/english/res_e/statis_e/statis_e.htm, accessed 15 September 2017.

Science and Engineering Indicators 2018

The EU is the second largest, with a global export share of 24%, but it has a substantial deficit. After falling from 26% to 20% between 2008 and 2012, the EU share rose to reach 24% between 2013 and 2016. Japan, the third largest (14% share), has a substantial trade surplus. Japan's global export share has remained stable between 2008 and 2016. For developing countries, receipts for the use of intellectual property are very low; for example, the global export shares of China and India were less than 0.5% in 2016 (Appendix Table 8-29).

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[1]Data on technology transfer metrics such as these are now increasingly available. Nonetheless, the federal technology transfer community has long recognized that counts of patent applications and awards, intellectual property licenses, cooperative research and development agreements, and the like do not usually of themselves provide a reasonable gauge of the downstream outcomes and impacts that eventually result from transfers—many of which involve considerable time and

many subsequent developments to reach full fruition. Literature on federal technology transfer success stories is growing, facilitated in part by the annual agency technology transfer performance reporting mandated by the Technology Transfer Commercialization Act of 2000 and through regularly updated reports by technology transfer professional organizations such as the Federal Laboratory Consortium for Technology Transfer (FLC). (For an ongoing, but selective, accounting of federal laboratory technology transfer success stories, organized by the FLC, see the "Success Stories" map in FLC [2017].) Even so, the documentation of these downstream outcomes and impacts remains well short of being complete.

[2] Differences in tax policies and protection of intellectual property also likely influence the volume and geographic patterns of global trade in royalties and fees (Gravelle 2010:8; Mutti and Grubert 2007:112).

[3] The volume and geographic patterns of U.S. trade in royalties and fees have been influenced by U.S.-based multinational companies transferring their intellectual property to low-tax jurisdictions or their foreign subsidiaries to reduce their U.S. and foreign taxes (Gravelle 2010:8; Mutti and Grubert 2007:112).

Innovation Indicators: United States and Other Major Economies

Inventions and knowledge transfer are two activities that provide the raw material for commercially viable, new, and improved products and processes. Indicators in this section focus more directly on ways these inputs create new value in the economy. This includes business investment in intangibles, such as software, R&D and artistic creations, private funding of innovation, government policies and programs intended to facilitate innovation, and firm-reported data on the introduction of new and improved products and processes. The chapter closes with indicators of economic impacts of innovation in the form of increased productivity, the creation of new firms, and the employment that results from these new firms.

Investment in Intangibles

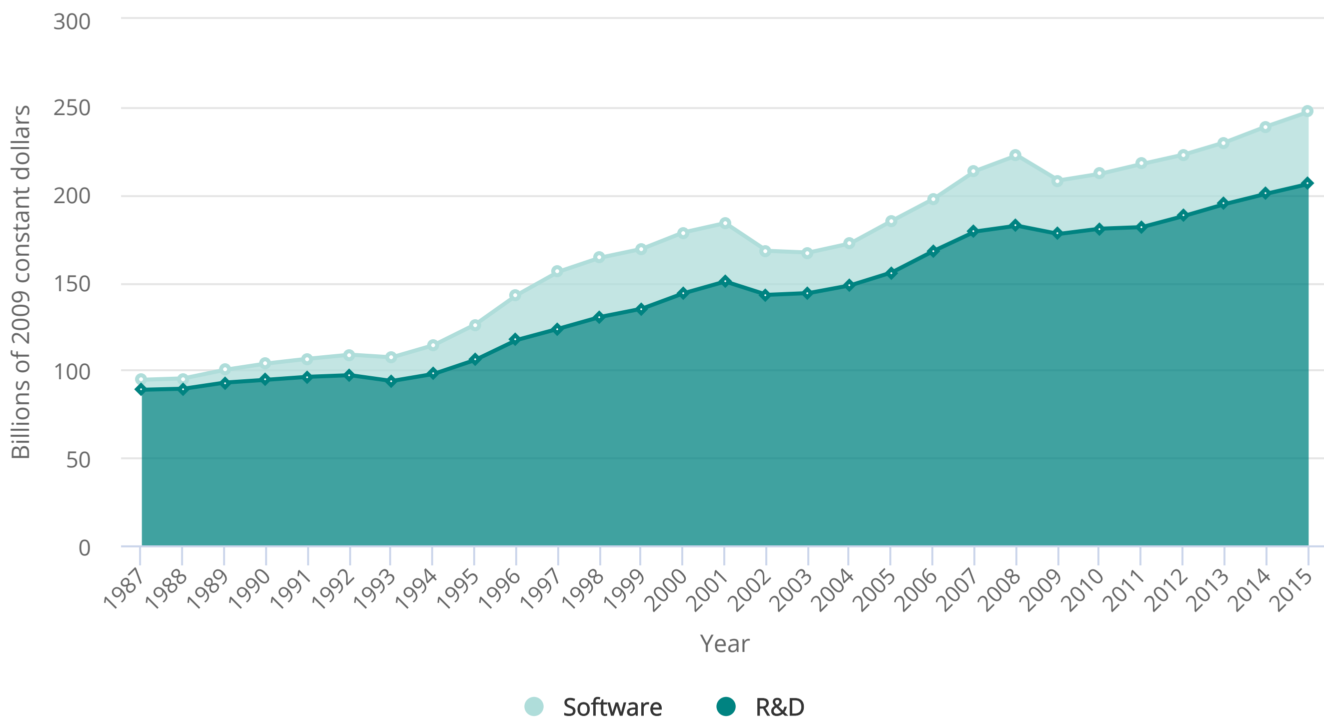
Intangibles in the economy include many services, such as insurance, education, telecommunications, as well as experiences such as concerts, movies, and sporting events; brand images; and embedded technology, such as software in cars and nutritionally enhanced food products (Blair and Wallman 2001).

Some intangibles once created provide benefits for years to come, for example computer software, R&D activity, designs and artistic creations. Often they can be simultaneously in more than one location, adding a dimension of use that tangibles do not possess. Digitization also allows many types of intangibles to be transmitted digitally across networks, multiplying potential impact further.

Gross domestic product (GDP) statistics for many countries, including the United States, include investment measures for the following types of intangible capital: computer software and databases, R&D expenditures, and artistic originals. Artistic originals are long-lived artwork produced by artists, studios, and publishers, including music, books, and programming, as measured by the Bureau of Economic Analysis (BEA) (Soloveichik and Wasshausen 2013) and tabulated by the U.S. Bureau of Labor Statistics as part of its measurement of productivity. Figure 8-14 and Figure 8-15 show investment for the U.S. manufacturing sector and for the nonfarm, nonmanufacturing sector in computer software, R&D, and artistic originals, adjusted for inflation with 2009 as the base year. The data are based on the categories used in the national income accounts. To prevent double counting in these measures, R&D directed toward the creation of computer software is categorized with computer software rather than with R&D (BEA 2013).

FIGURE 8-14

Private investment in intangibles, by type, for the manufacturing sector: 1987–2015



Note(s)

Investment in artistic originals is not estimated for manufacturing.

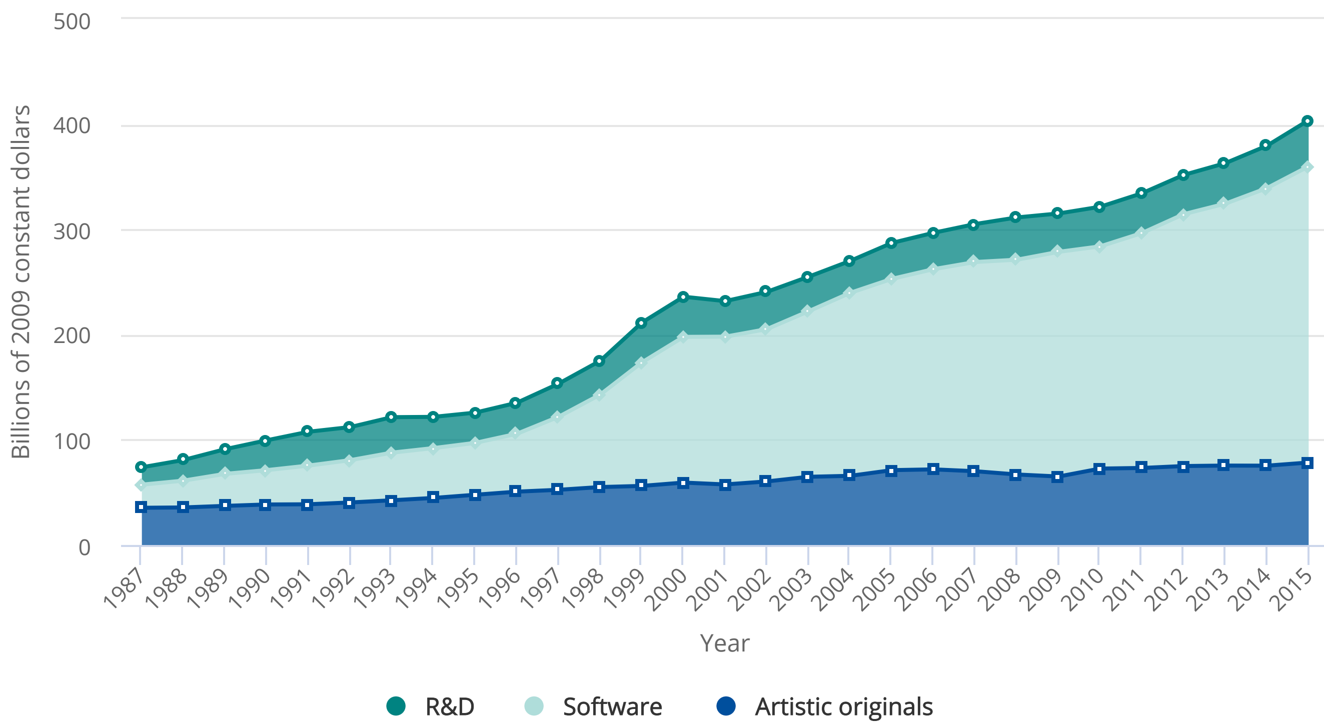
Source(s)

Bureau of Labor Statistics, Intellectual Property Products, Private Business Sector, https://www.bls.gov/mfp/mprdload.htm#CapitalTables, accessed 30 August 2017.

Science and Engineering Indicators 2018

FIGURE 8-15

Private investment in intangibles, by type, for the nonmanufacturing sector: 1987–2015



Note(s)

Measured in 2009 constant dollars, farm sector is not included in these measures.

Source(s)

Bureau of Labor Statistics, Intellectual Property Products, Private Business Sector,

https://www.bls.gov/mfp/mprdload.htm#CapitalTables, accessed 30 August 2017.

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Outside of manufacturing, the relative magnitudes of R&D and computer software investment differ and software investment comprises a much larger share of overall investment in intangibles. In the nonmanufacturing sector, investment in computer software in 2015 ($282 billion) is more than six times as large as that of the manufacturing sector ($41 billion) (Figure 8-15). Additionally, investment in artistic originals is considerably larger than in R&D. In 2015, investment in these artistic originals was $78 billion. Digitization and networking allow these originals to be transformed into downloadable and streaming services; such services are increasingly consumed using personal devices such as laptops, tablets, and cell phones.

The indicators presented cover important, but not all, types of intangible capital. Some firm investments are in the human capital embedded in people. Formal investments in education, training, and health; and experience gained through on-the-job training and other activities may be not only capital for the individual but also for the firm. A broader perspective on intangible capital suggests that all investments in intangibles that firms use repeatedly over time should be treated as capital assets. Other types of activities that could be included as intangible capital include spending on designs, spending to develop and protect brands, spending to develop human capital in the firm, and spending devoted to organizational development (Corrado, Hulten, and Sichel 2005, 2007).

Venture Capital

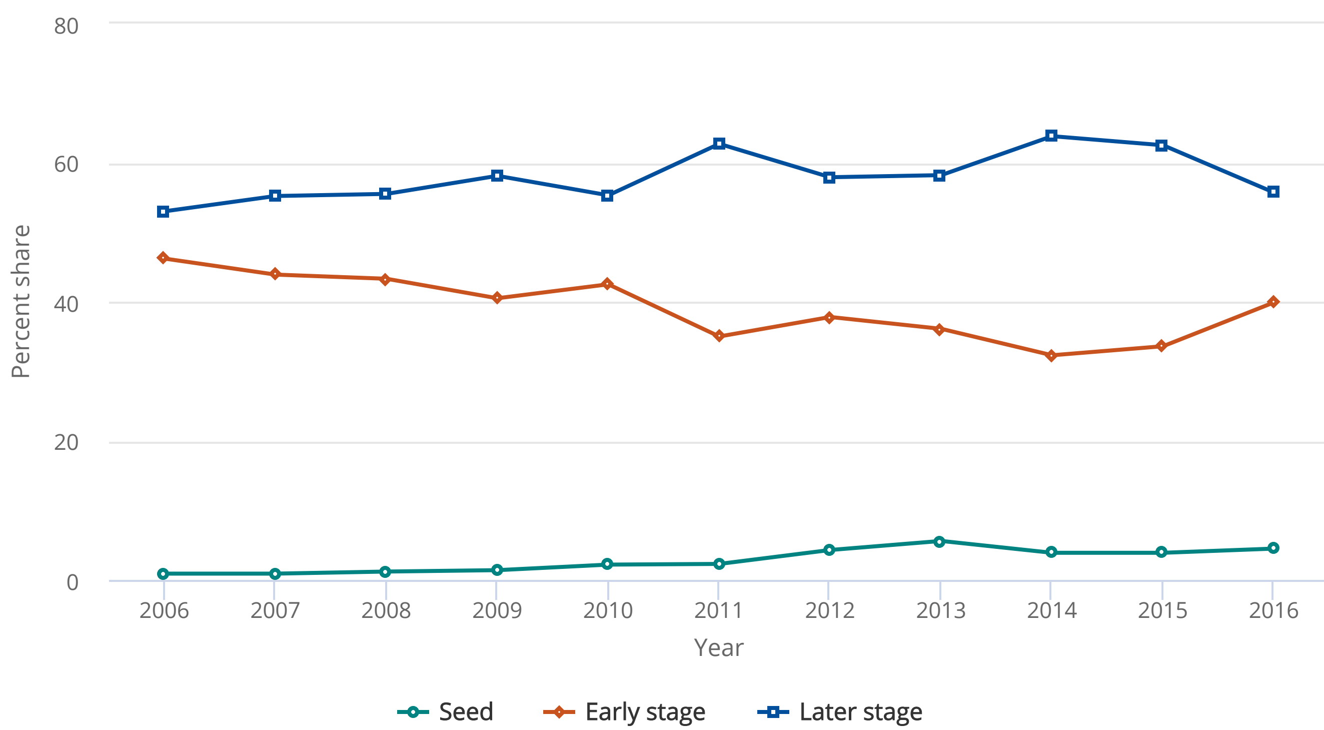
Access to financing is an essential component of the translation of inventions to innovations. Entrepreneurs seeking to start a new firm to commercialize a nascent or emerging technology rely on several funding sources: the entrepreneur's own funds, friends and family, bank loans, venture capital, angel investment, and government support (OECD 2014:174). Patterns and trends in venture capital investment are an indicator of support for emerging technologies that could make their way into the economy or are increasing their use in the economy. Venture capital investment is also an important financing source for existing high-technology firms that are commercializing technology. This section uses data from PitchBook, a company that collects comprehensive global data on venture capital and other early-stage investment.

Venture capital investment is generally categorized into three broad stages of financing—seed stage, early stage, and later stage. Seed-stage financing supports proof-of-concept development and initial product development and marketing and is important for understanding emerging technology trends. Global seed-stage venture capital investment was $6 billion in 2016, accounting for a very small share (4%) of total venture capital investment (Figure 8-16; Appendix Table 8-30). Early-stage financing accounted for 40% ($52 billion) of total venture capital investment in 2016. Early-stage financing supports product development and marketing and the initiation of commercial manufacturing and sales (Figure 8-16; Appendix Table 8-30); it also supports company expansion and provides financing to prepare for an initial public offering (IPO). Later-stage financing accounted for 56% ($73 billion in 2016) of total venture capital financing. Later-stage financing includes acquisition financing and management and leveraged buyouts. Acquisition financing provides resources for the purchase of another company, and management and leveraged buyouts provide funds to enable operating management to acquire a product line or business from a public or a private company.

Venture capital has been highly concentrated in early- and later-stage financing over the last decade and a half (Figure 8-16). The limited amount of seed-stage financing has been attributed to the reluctance of venture capitalists to invest in the uncertain and risky state of new product development (World Bank 2010:90). The difficulty of entrepreneurs obtaining seed-stage financing contributes to the "valley of death," the inability of new and nascent firms to obtain financing to commercialize their inventions and technology (OECD 2014:174).

FIGURE 8-16

Global venture capital investment, by financing stage: 2006–16



Note(s)

Venture capital investment does not include pre-incubator, accelerator, or angel investment. Seed financing supports proof-of-concept development and initial product development and marketing. Early-stage financing supports product development and marketing, the initiation of commercial manufacturing, and sales; it also supports company expansion and provides financing to prepare for an initial public offering. Later-stage financing includes acquisition financing and management and leveraged buyouts.

Source(s)

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

Science and Engineering Indicators 2018

Seed-Stage Venture Capital Investment

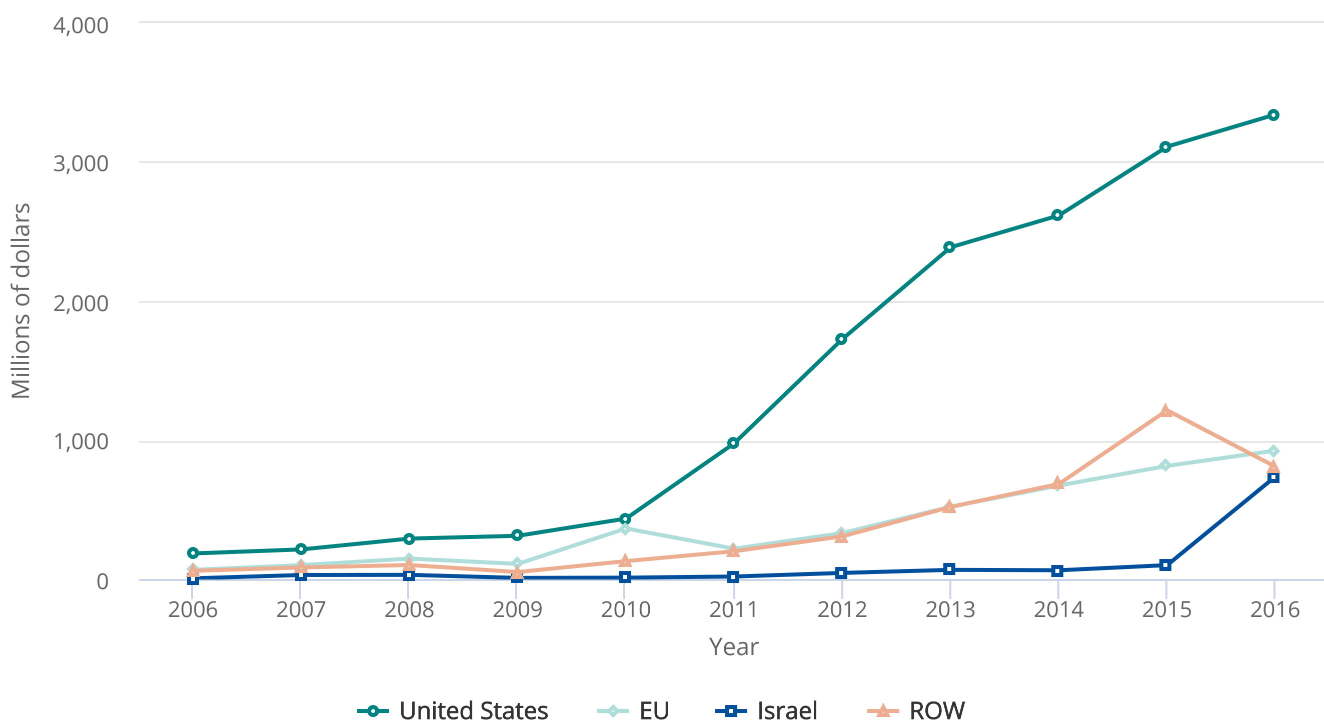
Global seed-stage venture capital investment was $5.8 billion in 2016 (Figure 8-17; Appendix Table 8-30). The United States received $3.3 billion, the largest share (58%) by far of any region or country. The EU and Israel were the second and third largest recipients, receiving $0.9 billion and $0.7 billion, respectively.

Global seed-stage investment has grown exponentially over the last decade, from more than $300 million in 2006 to $5.8 billion in 2016 (Figure 8-17 and Figure 8-18; Appendix Table 8-30); its growth rate (34% annualized average rate) was more than double that of early- and later-stage investment (13% annualized average rate), resulting in the seed-stage share of total investment increasing from 1% to 4% (Figure 8-18). Despite its strong growth over the last decade, seed stage remains a very small share of total venture capital investment.

In the United States, seed-stage financing grew from less than $200 million in 2006 to $3.3 billion in 2016 (Figure 8-17; Appendix Table 8-30). Like global trends, it grew far more rapidly (34% annualized average) than total U.S. early- and later-stage investment (9% annualized average).

FIGURE 8-17

Seed-stage venture capital investment, by selected country or economy: 2006–16



EU = European Union; ROW = rest of world.

Note(s)

Seed-stage venture capital financing supports proof-of-concept development and initial product development and marketing for startups and small firms that are developing new technologies. EU consists of present 28 member countries.

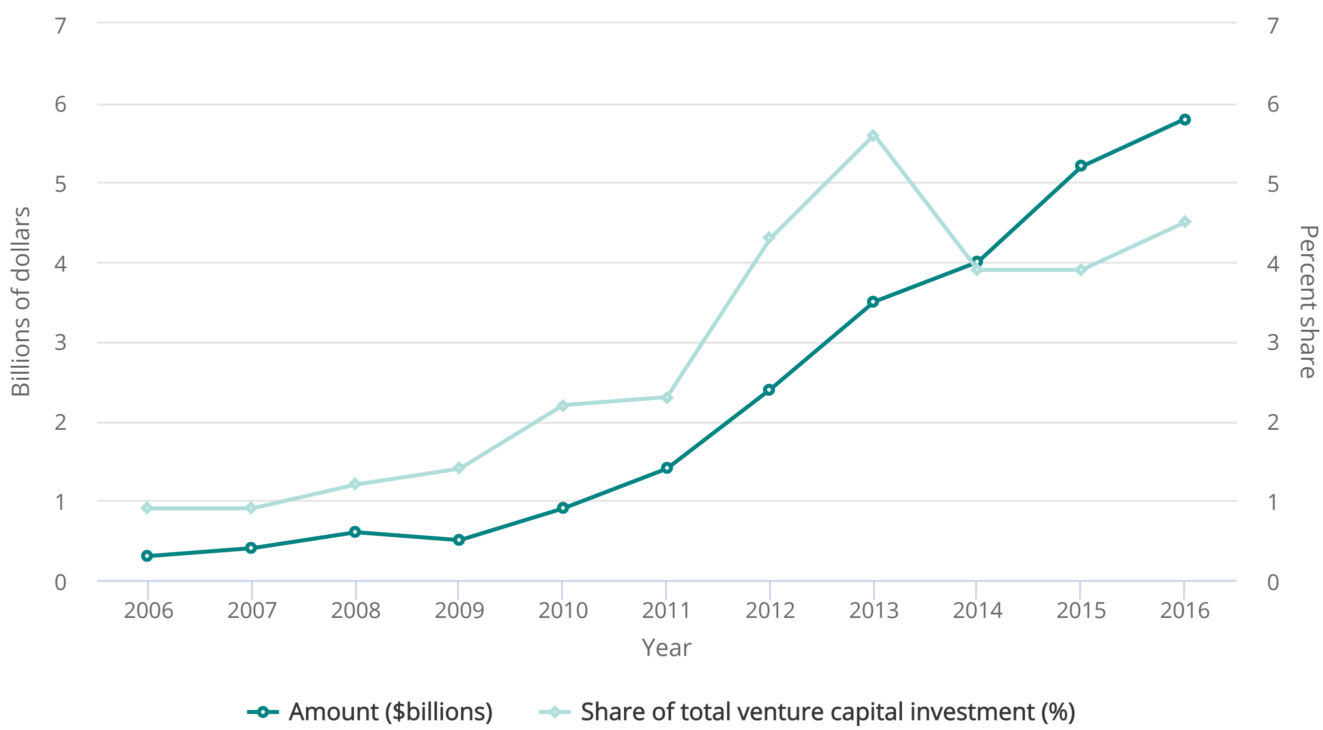
Source(s)

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

Science and Engineering Indicators 2018

FIGURE 8-18

Global seed-stage venture capital investment: 2006–16



Note(s)

Seed-stage financing supports proof-of-concept development and initial product development and marketing for startups and small firms that are developing new technologies.

Source(s)

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

Science and Engineering Indicators 2018

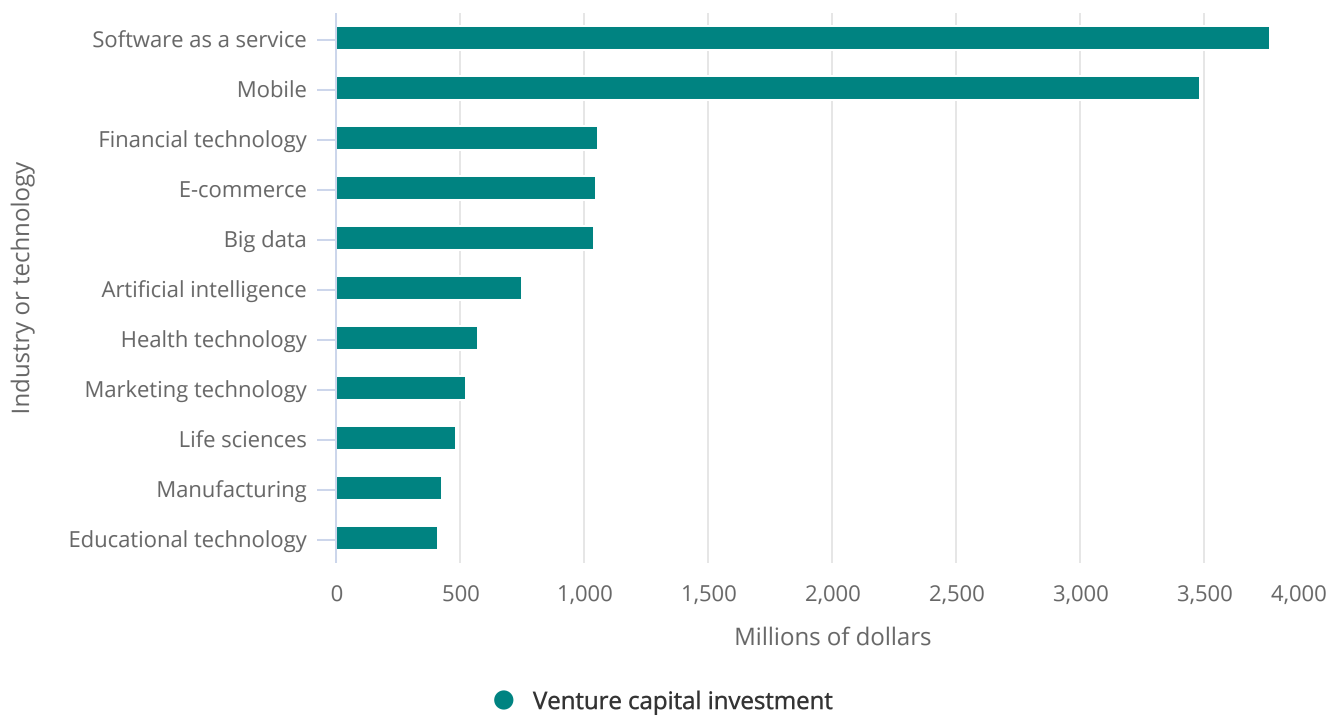
U.S. seed-stage venture capital investment by industry

PitchBook classifies firms that receive venture capital investment by industry (Appendix Table 8-31). Venture capital-backed firms that operate in multiple industries are classified in multiple industries. Classifying firms in multiple industries gives a more comprehensive picture compared with single industry classification because many firms produce products and services in multiple and diverse industries. The disadvantage is that the sum of venture capital investment in multiple industries exceeds total investment because of the double counting of investment in companies that are classified in multiple industries.

Between 2011 and 2016, the two industries that received the largest amount of seed-stage investment were software as a service ($3.8 billion) and mobile ($3.5 billion) (Figure 8-19; Appendix Table 8-32). Industries that received between $0.8 billion and $1.1 billion were financial technology, e-commerce, big data, and artificial intelligence. (Big data consist of companies that provide a product or service that is too large for traditional database systems.) Artificial intelligence, consisting of a variety of technologies, including software, natural language processing, and optical character recognition technology that has close ties to science, received $0.8 billion. Life sciences, a technology that is also closely tied to basic research in biotechnology and pharmaceuticals, received $0.5 billion.

FIGURE 8-19

U.S. seed-stage venture capital investment, by selected industry: 2011–16



Note(s)

Seed-stage financing supports proof-of-concept development and initial product development and marketing for startups and small firms that are developing new technologies. Industries ranked by the sum of investment between 2011 and 2016. Firms that receive venture capital investment are classified by industry. The sum of investment in industies exceeds total investment because firms that have activities in multiple industries are classified in multiple industries.

Source(s)

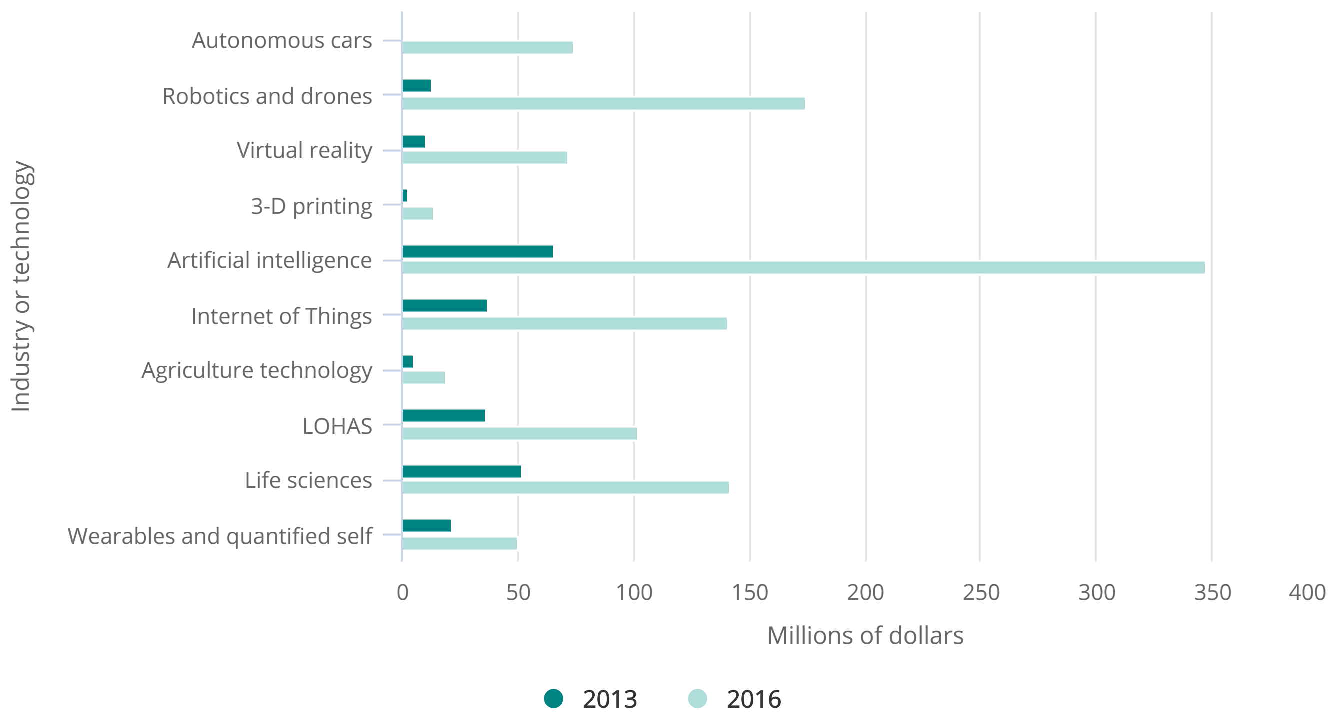
PitchBook, venture capital and private equity database, https://my.pitchbook.com/.

Science and Engineering Indicators 2018

Industries that have rapid increases in seed-stage investment may indicate nascent or emerging technologies. Investment in autonomous cars went from zero in 2013 to $74 million in 2016 (Figure 8-20; Appendix Table 8-32). Investment in the early- and later stages also grew very rapidly in this industry (Figure 8-21). (See the discussion in section U.S. early- and later-stage venture capital investment by industry.) Robotics and drones had the largest increase from 2013 to 2016 in investment (139% annualized average rate), reaching $175 million in 2016. Investment in virtual reality grew at a 91% annualized average rate to reach $72 million; early- and later-stage investment also rapidly increased (Figure 8-21). Artificial intelligence grew by a 74% annualized average rate between 2013 and 2016 to reach $347 million, the highest level of investment among fast-growing industries in 2016. Investment in the Internet of Things was robust (56% annualized average rate), reaching $141 million. (See Chapter 6 sidebar The Internet of Things for a discussion of these technologies.) Investment in life sciences, an area that includes pharmaceuticals and biotechnology that is closely linked to basic science, grew more slowly (39% annualized average rate between 2013 and 2016), also reaching $141 million.

FIGURE 8-20

U.S. seed-stage venture capital investment, by selected industry: 2013 and 2016



LOHAS = lifestyles of health and sustainability.

Note(s)

Quantified self is the use of technology to collect data about one's self. Seed-stage financing supports proof-of-concept development and initial product development and marketing for startups and small firms that are developing new technologies. Venture capital investments in firms are classified into industry verticals. The sum of investment in industry verticals exceeds total investment because firms that have activities in multiple industries are classified in multiple industries. Industries ranked by the largest increase in investment between 2013 and 2016.

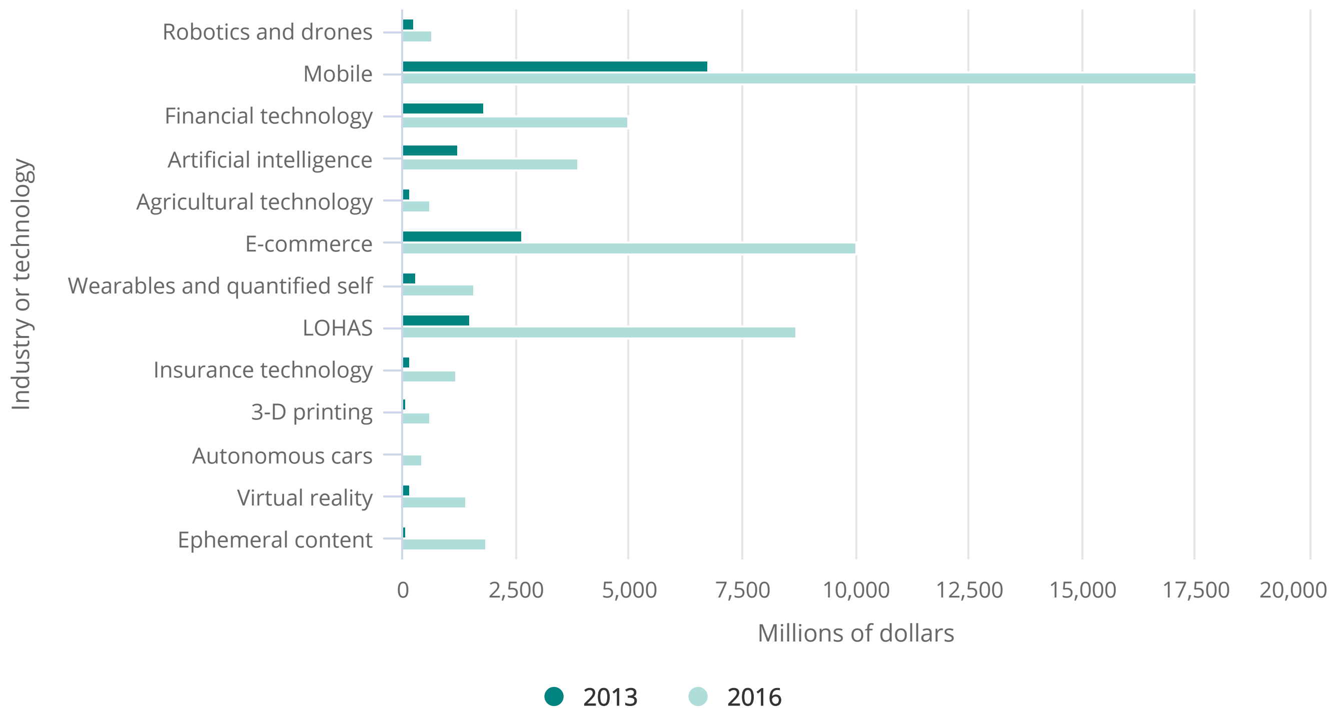
Source(s)

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

Science and Engineering Indicators 2018

FIGURE 8-21

U.S. early- and later-stage venture capital investment, by selected industry: 2013 and 2016



LOHAS = lifestyles of health and sustainability.

Note(s)

Quantified self is the use of technology to collect data about one's self. Early-stage financing supports product development and marketing, the initiation of commercial manufacturing, and sales; it also supports company expansion and provides financing to prepare for an initial public offering. Later-stage financing includes acquisition financing and management and leveraged buyouts. Venture capital investments in firms are classified into industry verticals. The sum of investment in industry verticals exceeds total investment because firms that have activities in multiple industries or technologies are classified in multiple industry verticals. Industries ranked by the largest increase in investment between 2013 and 2016.

Source(s)

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

Science and Engineering Indicators 2018

Early- and Later-Stage Venture Capital Investment

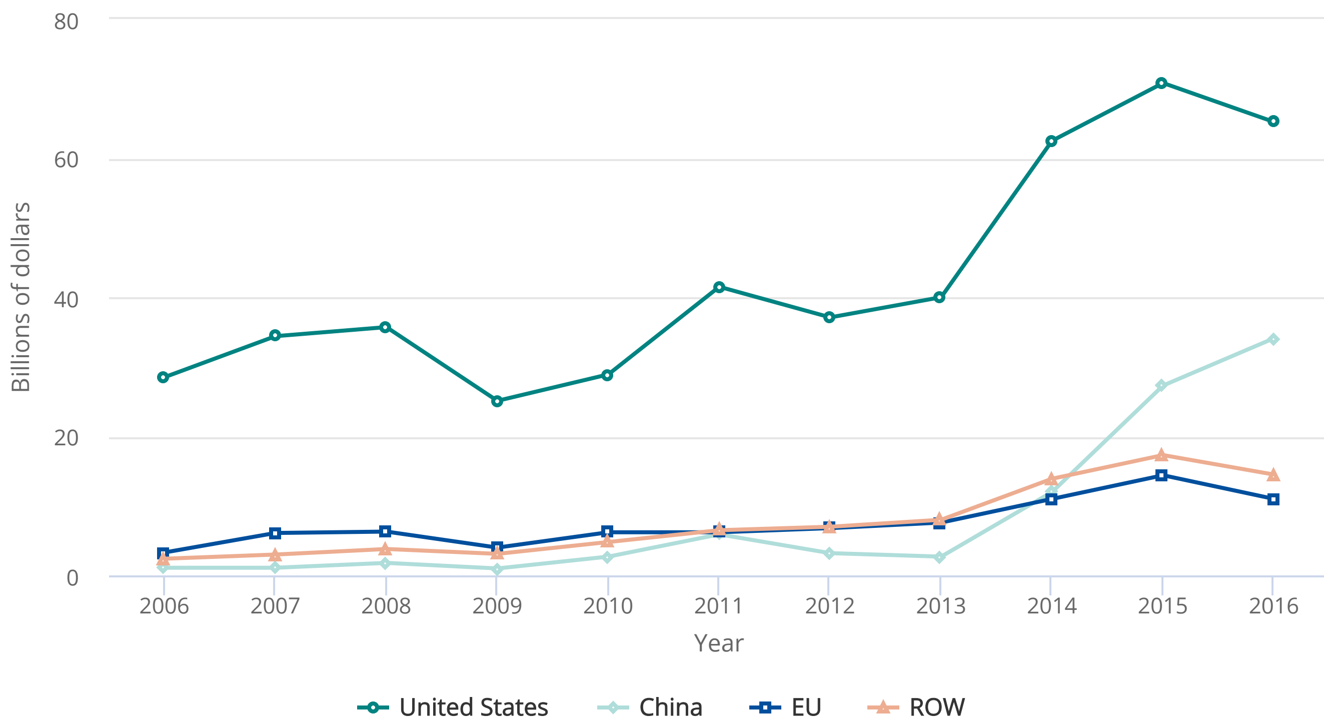
Global early- and later-stage venture capital investment was $125 billion in 2016 (Figure 8-22; Appendix Table 8-30). The United States attracted the most investment ($65 billion) of any region or country, accounting for slightly more than half of global investment. China attracted the second largest amount of investment ($34 billion) with a global share of 27%. The EU attracted the third largest amount ($11 billion).

Between 2006 and 2013, early- and later-stage global venture capital investment remained annually in the range of $30–$60 billion before surging to $99 billion in 2014 (Figure 8-22; Appendix Table 8-30). After increasing by 31% to $130 billion in 2015, investment fell slightly to $125 billion in 2016 because of high valuations of venture-backed companies, the lack of exits of existing venture-backed firms, and political and economic uncertainties (KPMG 2017:7).

Investment in China soared from $3 billion in 2013 to $34 billion in 2016, the largest increase of any country (Figure 8-22). China's share of global investment climbed from 5% in 2013 to 27% in 2016. The rise of China's middle class with disposable income and the government's focus on promoting domestic innovation have prompted major investments by private venture firms based in China and other countries, largely from the United States. The Chinese government has also created almost 800 public-backed venture capital funds that have raised more than $300 billion to invest in China (Oster and Chen 2016).

FIGURE 8-22

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



EU = European Union; ROW = rest of world.

Note(s)

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

Source(s)

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

Science and Engineering Indicators 2018

Early- and later-stage venture capital investment in the United States rose sharply (63%) to reach $65 billion between 2013 and 2016. Despite the robust growth in U.S. investment, the U.S. global share dropped from 69% in 2013 to 52% in 2016 due to more rapid growth in China. One factor that has driven the growth in U.S. investment is Chinese-based venture capital investors who have invested heavily in U.S. startups and venture-backed firms; one source estimates that about one-quarter of venture capital invested in the United States in 2015 originated from China (Oster and Chen 2016). China's growing wealth and the government's push to develop innovative high technologies have prompted Chinese-based companies and wealthy individuals to invest in U.S. startups and acquire technology (Dwoskin 2016).

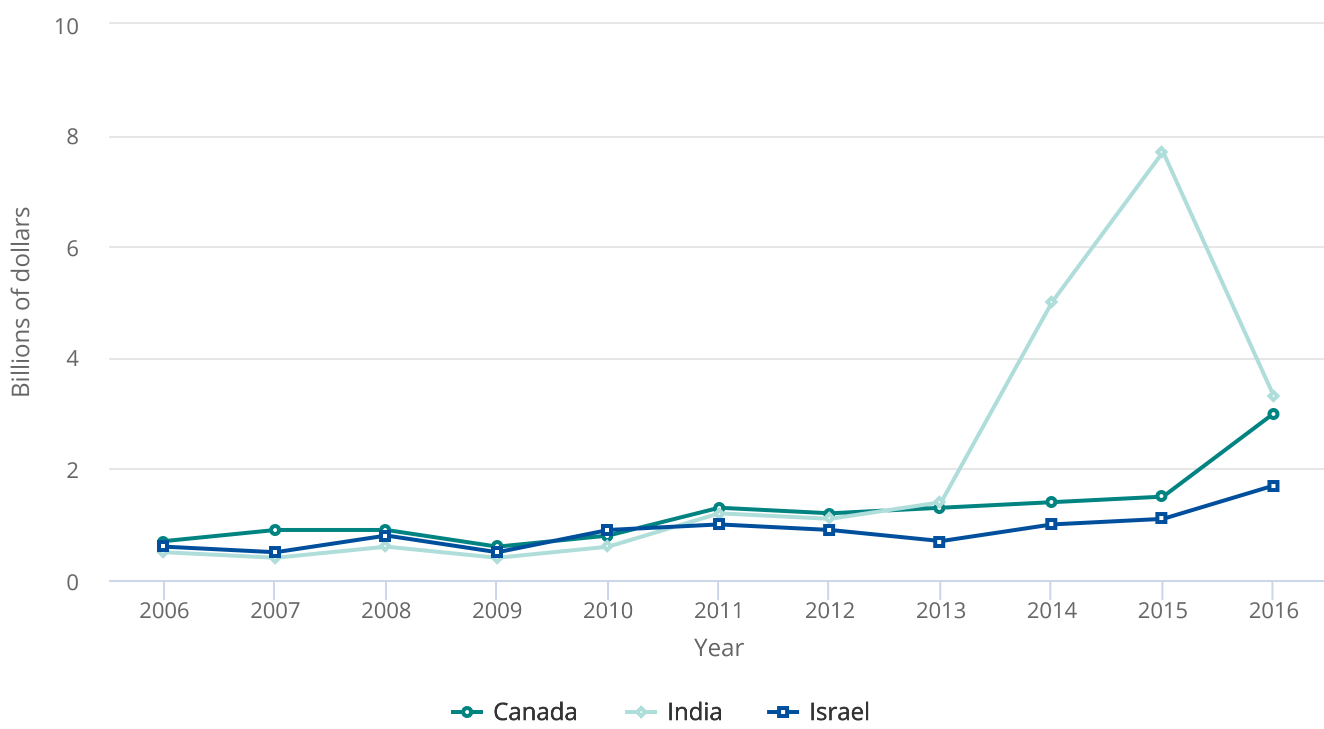
In other regions and economies, investment in the EU rose from $6 billion in 2013 to $11.0 billion in 2016 (Figure 8-22; Appendix Table 8-30). After spiking from $1.4 billion in 2013 to $7.7 billion in 2015, investment in India fell to $3.3 billion in

2016, more than double its level in 2013 (Figure 8-23). The spike in venture capital funding has been due to several factors, including the election of the first single-party government in 30 years, strong macroeconomic fundamentals, India's focus on S&T in higher education, and the country's strong position and expertise in business services and e-commerce.[1]

Investment in Israel more than doubled from $0.7 billion in 2013 to $1.7 billion in 2016 (Figure 8-23; Appendix Table 8-30). The expansion of venture capital outside of the United States, particularly in China, coincides with the globalization of finance, greater commercial opportunities in rapidly growing developing countries, and the decline of yields on existing venture capital investments in U.S.-based companies.[2]

FIGURE 8-23

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



Note(s)

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

Source(s)

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

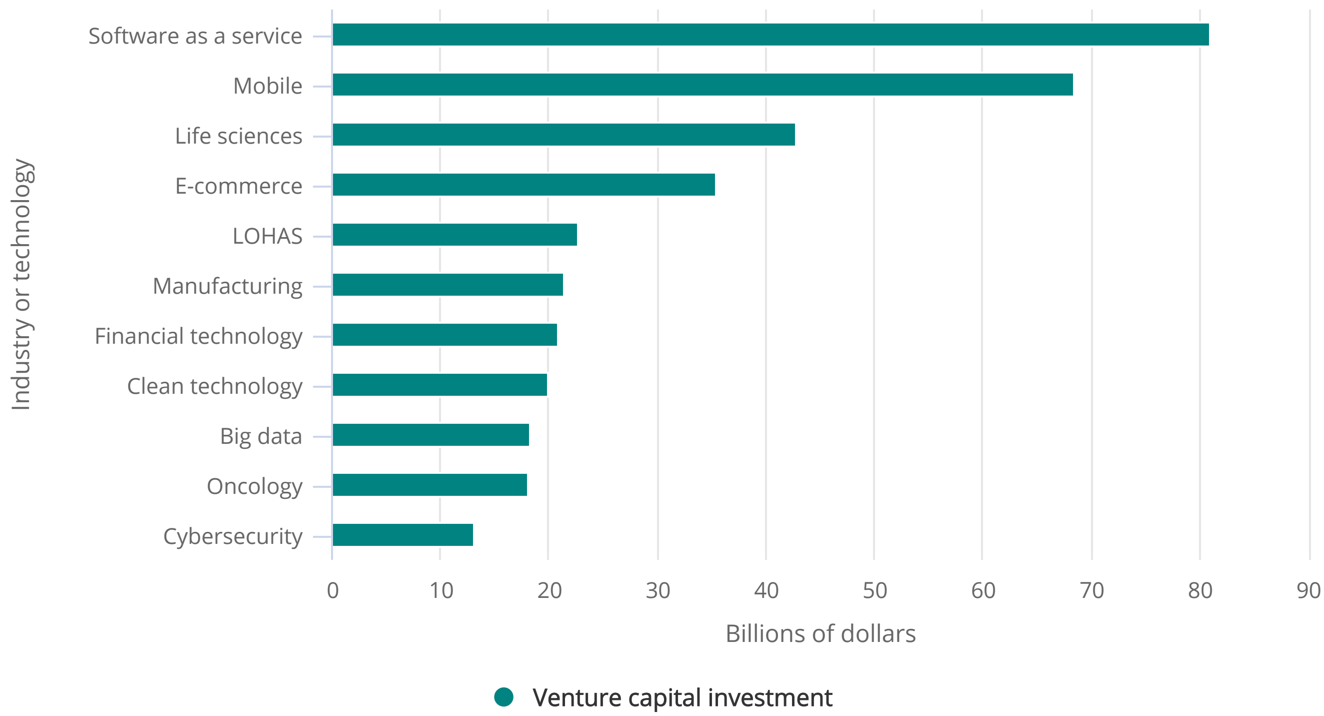
Science and Engineering Indicators 2018

U.S. early- and later-stage venture capital investment by industry

Between 2011 and 2016, software as a service ($81 billion) and mobile ($68 billion) received the largest total amount of early- and later-stage venture capital investment (Figure 8-24; Appendix Table 8-33). These two industries also received the largest amounts of seed-stage investment during this period. The next two largest were life sciences ($43 billion) and e-commerce ($35 billion)—the former being a technology that is closely tied to basic science. Four industries—lifestyles of health and sustainability, manufacturing, financial technology, and clean technology—each received $20 billion to $23 billion. Big data received comparatively less early- and later-stage investment ($18 billion), although it ranked high in seed-stage investment (Figure 8-19).

FIGURE 8-24

U.S. early- and later-stage venture capital investment, by selected industry: 2011–16



LOHAS = lifestyles of health and sustainability.

Note(s)

Early-stage financing supports product development and marketing, the initiation of commercial manufacturing and sales; it also supports company expansion and provides financing to prepare for an initial public offering. Later-stage financing includes acquisition financing and management and leveraged buyouts. Industries ranked by the sum of investment between 2011 and 2016. Venture capital investments in firms are classified into industry verticals. The sum of investment in industry verticals exceeds total investment because firms that have activities in multiple industries or technologies are classified in multiple industry verticals.

Source(s)

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

Science and Engineering Indicators 2018

Rapidly growing early- and later-stage investment in industries may be an indication that these areas are maturing and moving from radical or transformative to more incremental technological change. Between 2013 and 2016, ephemeral content, technologies that provide online sharing and temporary display of photographs and other content, had the most rapid growth in investment (193% annualized average) among all industries, soaring from $74 million to $1.9 billion (Figure 8-21; Appendix Table 8-33). More than 20 companies, including Snapchat, Instagram, and Periscope, have received venture capital financing for this rapidly growing sector.[3] Venture capital and other investors sold Snapchat to the public in a IPO in March 2017 (Balakrishnan 2017).[4]

Investment in virtual reality grew the second fastest (104% annualized average rate), rising from $164 million to $1.4 billion (Figure 8-21; Appendix Table 8-33). Autonomous cars had the third fastest increase (102% annualized average), jumping from $56 million to $459 million. More than 70 companies, including Tesla, Mobileye, and Delphi Automotive, have received venture capital financing in this sector to develop software, computers, cameras, radar sensors, and other technologies.[5] Most major automakers are conducting pilot tests of autonomous cars or have made large investments in or acquisitions of companies with autonomous driving technologies (Gates et al. 2016).

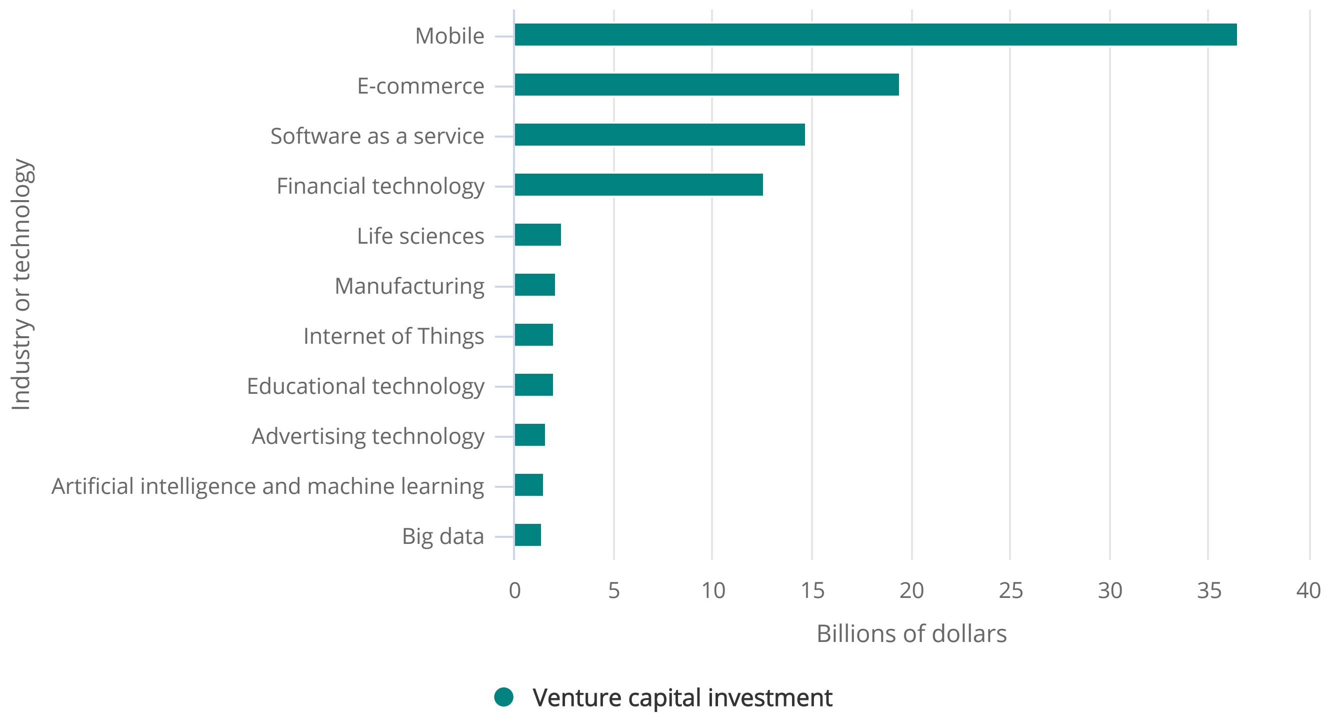
Investment in three-dimensional printing increased from $86 million to $612 million (92% annualized average). Lifestyles of health and sustainability grew the sixth fastest (79% annualized average rate), from $1.5 billion to $8.7 billion in 2016. (Lifestyles of health and sustainability consists of companies that provide consumer products or services focused on health, the environment, green technology, social justice, personal development, and sustainable living.) Early- and later-stage investment in artificial intelligence and machine learning, which has rapidly growing seed-stage investment, rose from $1.2 billion in 2013 to $3.9 billion in 2016.

Early- and later-stage venture capital investment in China by industry

Between 2011 and 2016, mobile technology was the leading industry receiving early- and later-stage investment ($37 billion) in China (Figure 8-25; Appendix Table 8-34). This industry received the second largest investment in the United States (Figure 8-24). E-commerce was the second largest ($19) in China and the fourth largest in the United States. Software as a service was the third largest, receiving $15 billion; this industry received the most investment in the United States. Life sciences, a technology that is closely tied to basic science, was the fifth largest, receiving comparatively little investment ($2 billion) compared with the four leading industries. This industry was the third largest in the United States, receiving far more investment ($43 billion) than in China.

FIGURE 8-25

China early- and later-stage venture capital investment, by selected industry: 2011–16



LOHAS = lifestyles of health and sustainability.

Note(s)

Early-stage financing supports product development and marketing, the initiation of commercial manufacturing, and sales; it also supports company expansion and provides financing to prepare for an initial public offering. Later-stage financing includes acquisition financing and management and leveraged buyouts. Amount of investment is the sum between 2011 and 2016. Venture capital investments in firms are classified into industry verticals. The sum of investment in industry verticals exceeds total investment because firms that have activities in multiple industries or technologies are classified in multiple industry verticals.

Source(s)

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

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Government Policies and Programs to Reduce Barriers to Innovation

Starting in the late 1970s, concerns by national policymakers about the comparative strength of U.S. industries and their ability to succeed in the increasingly competitive global economy took on greater intensity. The issues raised included whether the new knowledge and technologies flowing from federally funded R&D were being effectively exploited for the benefit of the national economy, whether pervasive barriers existed in the private marketplace that worked to slow businesses in exploiting new technologies for commercial applications and implementing innovations, and whether better public-private partnerships for R&D and business innovation had the potential to enhance the nation's economy to respond to these emerging challenges (Tassey 2007). There was also a concern about how to avoid inappropriately placing the government in positions to substitute for private business decisions better left to the competitive marketplace.

Many national policies and related programs have been directed at these challenges over the last 30 years. One major national policy thrust has been to enhance formal mechanisms for transferring knowledge arising from federally funded and performed R&D (Crow and Bozeman 1998; National Research Council [NRC] 2003), a topic discussed in the chapter's previous section. Another important development has been clearer recognition by policymakers, entrepreneurs, and the investment capital sector that structural and market barriers—often termed technological and commercial "valleys of death"—can arise in the marketplace that create difficult-to-bridge gaps for the innovation process and all too many barrier-filled pathways for otherwise promising new technologies (Branscomb and Auerswald 2002; Jenkins and Mansur 2011). These insights and an associated set of diagnostic concepts have given rise to several government programs intended to address the main sources for the gaps, with the intent of strengthening the prospects for the development and flow of early-stage technologies into the commercial marketplace. Other policy initiatives have included a particular focus on accelerating the commercial exploitation of academic R&D and encouraging the conduct of R&D on ideas and technologies with commercial potential by entrepreneurial small and/or minority-owned businesses.

The sections immediately following focus on this second theme of the commercial exploitation of federally funded R&D and review status indicators for several significant federal policies and programs directed at these objectives.

Small Business Innovation–Related Programs

The Small Business Innovation Research (SBIR) program and Small Business Technology Transfer (STTR) program are longstanding federal programs that provide competitively awarded funding to small businesses for purposes including stimulating technological innovation, addressing federal R&D needs, increasing private-sector commercialization of innovations flowing from federal R&D, and fostering technology transfer through cooperative R&D between small businesses and research institutions. The U.S. Small Business Administration (SBA) provides overall coordination for both programs, with implementation by the federal agencies that participate (SBA 2015).

The SBIR program was established by the Small Business Innovation Development Act of 1982 (P.L. 97–219) to stimulate technological innovation by increasing the participation of small companies in federal R&D projects, increasing private-sector commercialization of innovation derived from federal R&D, and fostering participation by minority and disadvantaged people in technological innovation. The program has received several extensions from Congress since then and is presently authorized through 2017. Eleven federal agencies participate in the SBIR program: USDA, DOC, DOD, the Department of Education, DOE, HHS, DHS, the Department of Transportation, the Environmental Protection Agency, NASA, and NSF.

The STTR program was established by the Small Business Technology Transfer Act of 1992 (P.L. 102–564, Title II) to facilitate cooperative R&D by small businesses, universities, and nonprofit research organizations and to encourage the transfer of technology developed through such research by entrepreneurial small businesses. Congress has likewise provided several extensions since it was initially enacted, with the program continuing through 2017. Five federal agencies participate in the STTR program: DOD, DOE, HHS, NASA, and NSF.

For SBIR, federal agencies with extramural R&D budgets exceeding $100 million annually must currently (FY 2017) set aside at least 3.2% for awards to U.S.-based small businesses (defined as those with fewer than 500 employees, including any affiliates). (The set-aside minimum was 2.5% for FYs 1997–2011, rising incrementally to 2.9% in FY 2015, 3.0% in FY 2016, and 3.2% in FY 2017.) Three phases of activities are recognized. In Phase I, a small company can apply for a Phase I funding award (normally not exceeding $150,000) for up to 6 months to assess the scientific and technical feasibility of an idea with commercial potential. Based on the scientific and technical achievements in Phase I and the continued expectation of commercial potential, the company can apply for Phase II funding (normally not exceeding $1 million) for 2 years of further development. Where the Phase I and II results warrant, the company pursues a course toward Phase III commercialization. The SBIR program itself does not provide funding for Phase III; depending on the agency, however, Phase III may involve non-SBIR-funded R&D or production contracts for products, processes, or services intended for federal government use. Several agencies offer bridge funding to Phase III and other commercialization support for startups (NRC 2008:208–16).

The initial round of SBIR awards was for FY 1983. This yielded 789 Phase I awards, across the participating agencies, for a total of $38.1 million of funding (Table 8-7; Appendix Table 8-35 and Appendix Table 8-36). The scale of the program expanded considerably thereafter. To date, the number of awards peaked in FY 2003, when the annual total of awards was 6,844 (5,100 Phase I awards and 1,744 Phase II awards). The peak in funding to date was FY 2010, with total funding of $2.300 billion ($565 million for Phase I awards and $1.735 billion for Phase II awards). More recently, however, the annual number of awards and funding totals have dropped somewhat (Table 8-7). In FY 2015, the award total was 4,508 (2,939 Phase I awards and 1,569 Phase II awards), with total funding of $1.923 billion ($462 million for Phase I awards and $1.461 billion for Phase II awards). In FY 2015, most funding reflected awards by DOD (49%) and HHS (22%) (Appendix Table 8-36). DOE (10%), NASA (8%), and NSF (7%) accounted for smaller shares. The other six participating agencies were 1% or less of the total.

TABLE 8-7

SBIR and STTR awards funding, by type of award: Selected years, FYs 1983–2015

(Number of awards and funding in millions of dollars)

Fiscal year	Number of awards			Funding ($millions)		
	Total	Phase I	Phase II	Total	Phase I	Phase II
SBIR						
1983	789	789	0	38.1	38.1	0.0
1985	1,838	1,483	355	195.3	74.5	120.8
1990	3,220	2,374	846	453.3	120.9	332.4
1995	4,367	3,092	1,275	962.2	236.5	725.8
2000	5,286	3,941	1,345	1,058.9	293.7	765.1
2005	6,085	4,216	1,869	1,862.5	452.5	1,410.0
2010	6,258	4,301	1,957	2,300.1	564.9	1,735.2
2011	5,403	3,628	1,775	2,052.4	507.6	1,544.8
2012	5,015	3,417	1,598	2,037.8	561.7	1,476.1
2013	4,520	3,017	1,503	1,927.0	489.9	1,437.1
2014	4,598	3,092	1,506	1,983.8	502.6	1,481.2
2015	4,508	2,939	1,569	1,922.8	462.0	1,460.8
STTR						
1983	na	na	na	na	na	na
1985	na	na	na	na	na	na
1990	na	na	na	na	na	na
1995	1	1	0	0.1	0.1	0.0
2000	410	315	95	64.0	23.7	40.3
2005	801	579	222	226.4	66.1	160.3
2010	903	625	278	298.7	78.9	219.8
2011	709	468	241	266.6	67.7	198.9
2012	637	467	170	222.5	73.1	149.4
2013	642	456	186	218.9	74.1	144.7

Fiscal year	Number of awards			Funding ($millions)		
	Total	Phase I	Phase II	Total	Phase I	Phase II
2014	703	493	210	284.2	95.1	189.1
2015	725	553	172	257.6	98.5	159.1

na = not applicable.

SBIR = Small Business Innovation Research; STTR = Small Business Technology Transfer.

Note(s)

The first SBIR program awards were made in FY 1983. The first STTR program award was made in FY 1995. Detail may not add to total due to rounding.

Source(s)

U.S. Small Business Administration, SBIR/STTR official website, https://www.sbir.gov/awards/annual-reports, accessed 1 March 2017. See Appendix Table 4-31 through Appendix Table 4-33.

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For the STTR program, federal agencies with extramural R&D budgets that exceed $1 billion annually must currently (FY 2017) reserve not less than 0.45% for STTR awards to small businesses. (The set-aside minimum was 0.3% for FYs 2004–11, rising incrementally to 0.4% in FYs 2014–15 and to 0.45% in FY 2016 and thereafter.) STTR operates within the same three-phase framework as SBIR. Phase I provides awards for company efforts to establish the technical merit, feasibility, and commercial potential of proposed projects; the funding in this phase normally does not exceed $100,000 over 1 year. Phase II is for continued R&D efforts, but award depends on success in Phase I and continued expectation of commercial potential. Phase II funding normally does not exceed $750,000 over 2 years. Phase III is for the small business to pursue commercialization objectives, based on the Phase I and II results. The STTR program does not provide funding for Phase III activities. Furthermore, to pursue Phase III, companies must secure non-STTR R&D funding and/or production contracts for products, processes, or services for use by the federal government.

The STTR program started with a single Phase I award for $100,000 in FY 1995 (Table 8-7; Appendix Table 8-35 and Appendix Table 8-37). This program has also expanded considerably in subsequent years. The peak years to date for number of awards were FY 2004, with a total of 903 awards (719 Phase I awards and 184 Phase II awards), and FY 2010, also with 903 awards (625 Phase I awards and 278 Phase II awards). The peak in total funding was $299 million in FY 2010 ($79 million for Phase I and $220 million for Phase II). In FY 2015, 725 awards were made (553 for Phase I and 172 for Phase II), with funding totaling $258 million ($99 million for Phase I and $159 million for Phase II). Fewer federal agencies participate in STTR, but those dominant in SBIR are also dominant in STTR. STTR awards from DOD accounted for 49% of the $258 million award total in FY 2015 (Appendix Table 8-37). HHS accounted for 24% of the STTR awards, and the remaining awards were from DOE (10%), NASA (9%), and NSF (8%).

Other Federal Programs

The federal policies, authorities, and incentives established by the Stevenson-Wydler Technology and Innovation Act (and the subsequent amending legislation) and the SBIR and STTR programs are far from the whole of federal efforts to promote the transfer and commercialization of federal R&D. Many programs for these purposes exist in the federal agencies. These programs typically have objectives that closely reflect the specifics of agency missions and draw resources at levels well below the federal-wide SBIR and STTR programs. Several of the larger programs currently run by federal R&D performing agencies are briefly described in Table 8-8. A larger group of such federal agency policies and programs is documented in Appendix Table 8-38. Following Table 8-8, commentary is offered on three particularly well-known programs: DOC's Hollings Manufacturing Extension Partnership, DOE's Advanced Research Projects Agency-Energy, and NSF's Industry/University Cooperative Research Centers.

TABLE 8-8

Examples of federal policies and programs supporting early-stage technology development and innovation

(Summary of program goals and activities for selected federal agencies)

Agency, office, and program
Department of Agriculture
Under Secretary for Research, Education, and Economics
Agricultural Research Service (ARS)
Program name: Agricultural Research Partnerships (ARP) Network
Program goals: The ARS founded the ARP Network to expand the impact of ARS research and provide resources to help ARS commercial partners grow.
Program activities: The ARP Network matches business needs with ARS innovations and research capabilities and provides business assistance services to help companies and startups solve agricultural problems, develop products, and create new jobs. The ARP Network assists ARS in creating new partnerships and in supporting existing partnerships to advance ARS R&D efforts and subsequent utilization, including commercialization. Some of the ARP Network activities include matching industry needs with ARS patents and researchers for partnering; providing access to ARS research expertise, facilities, and equipment; and assisting in identifying sources of funding. The ARP Network is composed of organizations interested in agriculture-based economic development.
Department of Defense
Department Wide
Program name: Manufacturing Technology (ManTech) Program
Program goals: The Defense-Wide Manufacturing Science & Technology (DMS&T) ManTech Program was established to address cross-cutting, game-changing initiatives that are beyond the scope of any one Military Department or Defense Agency.
Program activities: ManTech seeks to address defense manufacturing needs, transition manufacturing R&D processes into production applications, attack manufacturing issues, and explore new opportunities.
Department of Health and Human Services

Agency, office, and program
National Institutes of Health (NIH)
National Center for Advancing Translational Sciences (NCATS)
Program name: Therapeutics for Rare and Neglected Diseases (TRND)
Program goals: The TRND program supports pre-clinical development of therapeutic candidates intended to treat rare or neglected disorders, with the goal of enabling an Investigational New Drug (IND) application to the Food and Drug Administration (FDA).
Program activities: The TRND program encourages and speeds the development of new treatments for diseases with high unmet medical needs. The program advances the entire field of therapeutic development by encouraging scientific and technological innovations to improve success rates in the crucial pre-clinical stage of development. TRND stimulates therapeutic development research collaborations among NIH and academic scientists, nonprofit organizations, and pharmaceutical and biotechnology companies working on rare and neglected illnesses. The program provides NIH's rare and neglected disease drug development capabilities, expertise, clinical resources, and regulatory expertise to research partners to optimize promising therapeutics and move them through pre-clinical testing, with the goal to generate sufficient-quality data to support successful IND applications and first-in-human studies in limited circumstances.
Department of Transportation
Federal Highway Administration (FHWA)
Office of Innovative Program Delivery
Program name: State Transportation Innovation Council (STIC) Incentive Program
Program goals: The STIC Incentive Program offers technical assistance and resources to support the standardization of innovative practices among state transportation agencies and other public sector stakeholders.
Program activities: The STIC Incentive Program provides up to $100,000 per State per Federal fiscal year to STICs to support or offset the costs of standardizing innovative practices in a State transportation agency (STA) or other public sector STIC stakeholder. STIC Incentive Program funding may be used to conduct internal assessments; build capacity; develop guidance, standards, and specifications; implement system process changes; organize peer exchanges; offset implementation costs; or conduct other activities the STIC identifies to address Technology and Innovation Deployment Program (TIDP) goals.
National Aeronautics and Space Administration
Human Exploration and Operations Mission Directorate

Agency, office, and program
Advanced Exploration Systems Division
Program name: Next Space Technologies for Exploration Partnerships (NextSTEP)
Program goals: The NextSTEP program is a public-private partnership model that encourages commercial development of deep space exploration capabilities to support more extensive human spaceflight missions in the Proving Ground around and beyond cislunar space—the space near Earth that extends just beyond the moon.
Program activities: NextSTEP stimulates the commercial space industry to help NASA achieve its strategic goals and objectives for expanding the frontiers of knowledge, capability, and opportunities in space. The NextSTEP partnership model provides an opportunity for NASA and industry to partner to develop capabilities that meet NASA human space exploration objectives while also supporting industry commercialization plans. Through these public-private partnerships, NextSTEP partners provide advance concept studies and technology development projects in the areas of advanced propulsion, habitation systems, and small satellites.
National Science Foundation
Directorate for Engineering
Division of Industrial Innovation and Partnerships (IIP)
Program name: Innovation Corps Program (I-Corps™; NSF, NIH, DoD, DoE, and USDA all have I-Corps programs)
Program goals: The I-Corps Program aims to foster entrepreneurship that will lead to the commercialization of technology that has been supported previously by NSF-funded research. The program provides entrepreneurial education for federally-funded scientists and engineers, pairing them with business mentors for an intensive curriculum focused on discovering a demand-driven path from their lab work to a marketable product.
Program activities: There are three distinct components of I-Corps: Teams, Nodes, and Sites. I-Corps Teams include NSF-funded researchers who will receive additional support—in the form of mentoring and funding—to accelerate innovation that can attract subsequent third-party funding. Nodes serve as hubs for education, infrastructure, and research that engage academic scientists and engineers in innovation; they also deliver the I-Corps Curriculum to I-Corps Teams. I-Corps Sites are academic institutions that catalyze the engagement of multiple, local teams in technology transition and strengthen local innovation.

Note(s)

The table summarizes examples of policy and program information collected during the spring and fall of 2017 from federal staff for a selected set of U.S. agencies with major R&D and technology development activities. The table reflects agency responses. For a fuller list of federal policies and programs see Appendix Table 8-38.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics; SRI International, special tabulations of federal program information (2017).

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Hollings Manufacturing Extension Partnership

The Hollings Manufacturing Extension Partnership (MEP) is a nationwide network of manufacturing extension centers located in all 50 states and Puerto Rico. MEP was created by the Omnibus Foreign Trade and Competitiveness Act of 1988 (P.L. 100–418) and is headed by DOC's NIST (DOC/NIST 2017). The MEP centers (which are nonprofit) exist as a partnership among the federal government, state and local governments, and the private sector. MEP provides technical expertise and other services to small and medium-sized U.S. manufacturers to improve their ability to develop new customers, expand into new markets, and create new products. The centers work directly with manufacturers to engage specific issues, including innovation and business strategies, product development and prototyping, lean and process improvements, workforce development, supply chain development, technology scouting, and transfer. The centers also serve to connect manufacturers with universities and research laboratories, trade associations, and other relevant public and private resources. The MEP annual report for FY 2015 (the most recent report presently available) describes the national network of MEP centers as operating with a total budget of about $300 million annually—$130 million from the federal government (with more than $110 million going directly to the centers), with the balance from state and local governments and the private sector (DOC/NIST 2015). The MEP report indicates that technical expertise and other services were provided during FY 2015 to 29,101 U.S. manufacturing companies and attributes impacts of $8 billion in increased or retained sales, 68,477 jobs created or retained, and $1.2 billion in cost savings for these businesses. (These services and impact metrics are comparable with the reports of recent previous years.)

Advanced Research Projects Agency–Energy

DOE's Advanced Research Projects Agency–Energy (ARPA-E) provides funding, technical assistance, and market development to advance high-potential, high-impact energy technologies that are too early-stage for private-sector investment (DOE 2017). The main interest is energy technology projects with the potential to radically improve U.S. economic security, national security, and environmental quality—in particular, short-term research that can have transformational impacts, not basic or incremental research. The America COMPETES Act of 2007 (P.L. 110–69) authorized ARPA-E, and it received $400 million of initial funding through the American Recovery and Reinvestment Act of 2009 (P.L. 111–5). Federal funding (appropriations) for ARPA-E was $180 million in FY 2011, $275 million in FY 2012, $251 million in FY 2013 (reduced by budget sequestration that year), and $280 million in FYs 2014 and 2015. ARPA-E's annual report for FY 2015 (most recent available) indicated 81 new project awards in FY 2015, with a total of 542 funded projects and $1.49 billion of funding since the program's inception (DOE 2015). The program identifies 31 focused and 2 open project areas, with topics including advanced batteries, transportation technologies, solar energy, energy storage technologies, advanced carbon capture technologies, electric power transmission, distribution and control, biofuels, and improved building energy efficiencies.

Industry/University Cooperative Research Centers

NSF's Industry/University Cooperative Research Centers (IUCRC) program supports industry-university partnerships to conduct industrially relevant fundamental research, collaborative education, and the transfer of university-developed ideas, research results, and technology to industry (NSF 2017). NSF supports IUCRC through partnership mechanisms where, per NSF, the federal funding is typically multiplied 10–15 times by supplementary funding from businesses and other nonfederal sources. The IUCRC program report for 2015–16 (NSF/IUCRC 2017) indicates 68 centers across the United States, with more than 1,000 nonacademic members: 85% are industrial firms, with the remainder consisting of state governments, national laboratories, and other federal agencies. NSF's IUCRC program funding for the centers was about $17.2 million that year, with other sources of support (including NSF funds other than the IUCRC program; member fees; funds from industry; and funds from other federal agencies, state government, and other nonfederal government), bringing the total of center funding that year to $109.3 million. Research is prioritized and executed in cooperation with each center's membership organizations.

Innovation Activities by U.S. Business

The data presented thus far on invention, knowledge transfer, and innovation provide insights into the sources of knowledge, inventions, and funding for innovation, as well as the efforts by government and academic institutions to facilitate technology transfer and the early-stage development of useful technologies. Yet none of these measures provide a clear indicator for the incidence of innovation in firms—the implementation of a new or significantly improved product or business process. Firm-level survey data collected in the United States, Europe, and parts of Latin America, Asia, the Pacific, and South Africa provide industry-level data on the incidence of innovations, as well as rich ancillary data on related activities in firms. See sidebar Concepts and Definitions for Business Innovation Survey Data for more information on the framework behind the U.S. survey data on innovation collected by the National Center for Science and Engineering Statistics BRDIS. This U.S. survey is also the source of the R&D expenditure data reported in Chapter 4.

SIDEBAR

Concepts and Definitions for Business Innovation Survey Data

The Oslo Manual of the Organisation for Economic Co-operation and Development (OECD) and Eurostat (2005) provides a definition for firm-level innovation activity that countries and economies have widely used to enhance comparability of international data. Survey data are guided by this framework including, notably, the Community Innovation Surveys (CIS) from the European Union (EU) Statistical Office and the Business R&D and Innovation Survey (BRDIS) from NSF's National Center for Science and Engineering Statistics. Following *The Oslo Manual*, innovation is defined in these surveys as "implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method" (OECD/Eurostat 2005:46–47).

The CIS is a coordinated effort at comparable innovation data across EU countries, conducted in 28 EU states, and used as the basis for other countries' data collection. For the EU states, data collection is coordinated and integrated by the European Commission. The OECD also uses these data in its international comparisons for the Science, Technology, and Industry Scoreboard (http://www.oecd.org/innovation/inno/inno-stats.htm#indicators).

BRDIS, described in Chapter 4 as the source of U.S. business R&D expenditures, includes innovation questions derived from *The Oslo Manual* and the CIS. However, the U.S. survey data identify only new or significantly improved products and processes. Examination has shown that organizational innovation, marketing innovation, and other process innovations are often not distinct enough to be divisible for respondent reporting, a finding supported empirically by cognitive interview data (Tuttle et al. 2013). Innovation data on this survey have been collected for nonfarm U.S. private industries with five employees or more since 2008.

Per NSF's BRDIS, 17% of U.S. firms (or companies) reported introducing a new or significantly improved product or process during 2013–15 (Table 8-9): 1 in 6 firms. This incidence rate of innovation varies across firm size and industry. Reported innovation rates increase overall with firm size. However, across all firms, more than 230,000 that have fewer than 250 employees (and at least 5) had introduced a product or process innovation. For large firms, those with 250 or more employees, more than 6,500 introduced innovations.

TABLE 8-9

U.S. companies introducing new or significantly improved products or processes, by company size and industry sector: 2013–15

(Number and percent)

Company size and industry	Companies (number)[a]	Percent reporting product and/or process improvements
All companies (number of domestic employees)	1,413,932	16.8
Micro-companies		
5–9	550,695	13.4
Small companies		
10–19	422,056	17.8
20–49	287,091	18.7
Medium companies		
50–99	82,729	22.4
100–249	46,480	20.9
Large companies		
250–499	13,024	24.2
500–999	5,535	17.9
1,000–4,999	4,918	35.8
5,000–9,999	541	29.5
10,000–24,999	363	33.8
25,000 or more	500	68.9
All companies with 5 or more domestic employees		
Manufacturing industries (NAICS 31–33)	112,782	33.1
Nonmanufacturing industries (NAICS 21–23, 42–81)	1,301,150	15.4

NAICS = North American Industry Classification System.

[a] Statistics for the number of companies are based only on companies in the United States that reported data for at least one of the items on the survey relating to new or significantly improved products or processes, regardless of whether the company performed or funded R&D. These statistics do not include an adjustment to the weight to account for unit nonresponse.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, and U.S. Census Bureau, Business R&D and Innovation Survey (BRDIS), 2015.

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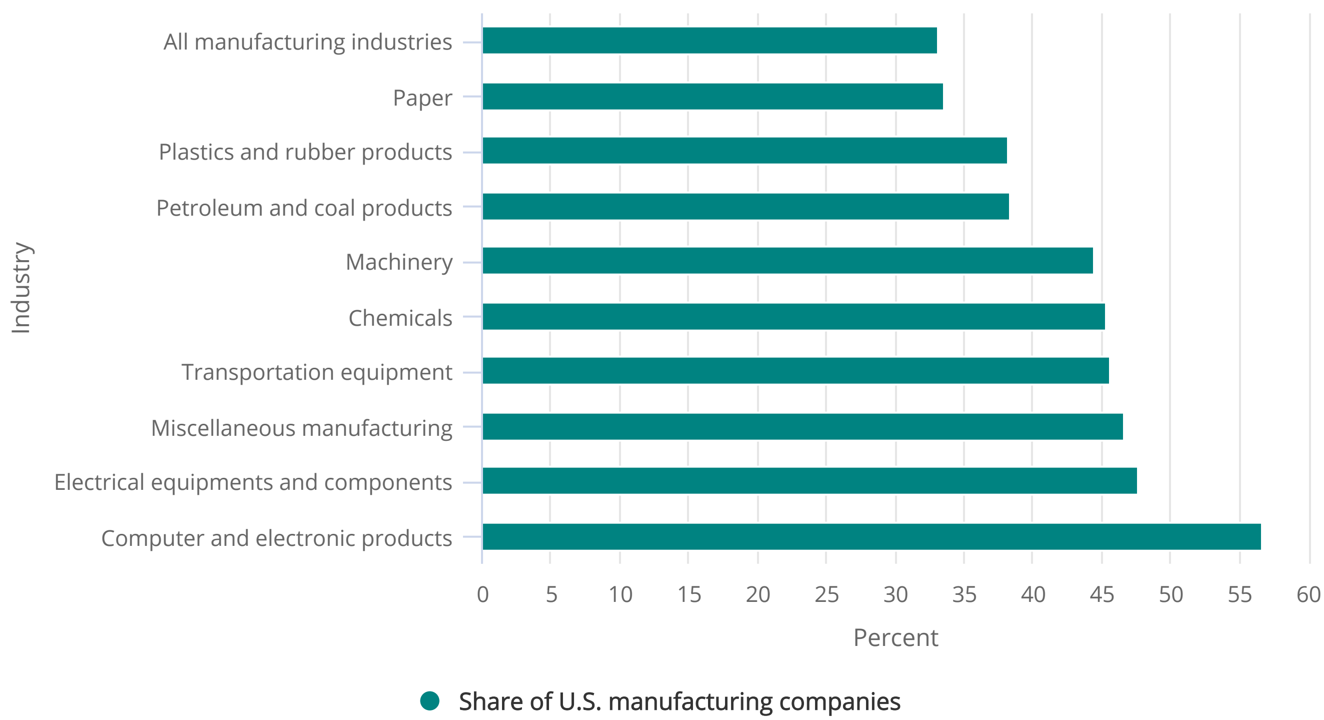
ICT-producing industries report many of the highest rates of innovation in manufacturing and in other sectors of the economy. Within manufacturing, almost half of electronic equipment and component firms, and more than half of computer and electronic products firms reported innovations between 2013 and 2015 (Figure 8-26). Outside of manufacturing firms, 44% of computer systems design firms and 31% of information industry firms reported innovations (Figure 8-27).

FIGURE 8-26

Share of U.S. manufacturing companies reporting product or process innovation, by selected industry: 2013–15



Note(s)

The survey asked companies to identify innovations introduced from 2013 to 2015. Electrical equipment includes appliances.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Business R&D and Innovation Survey (BRDIS) (2015)

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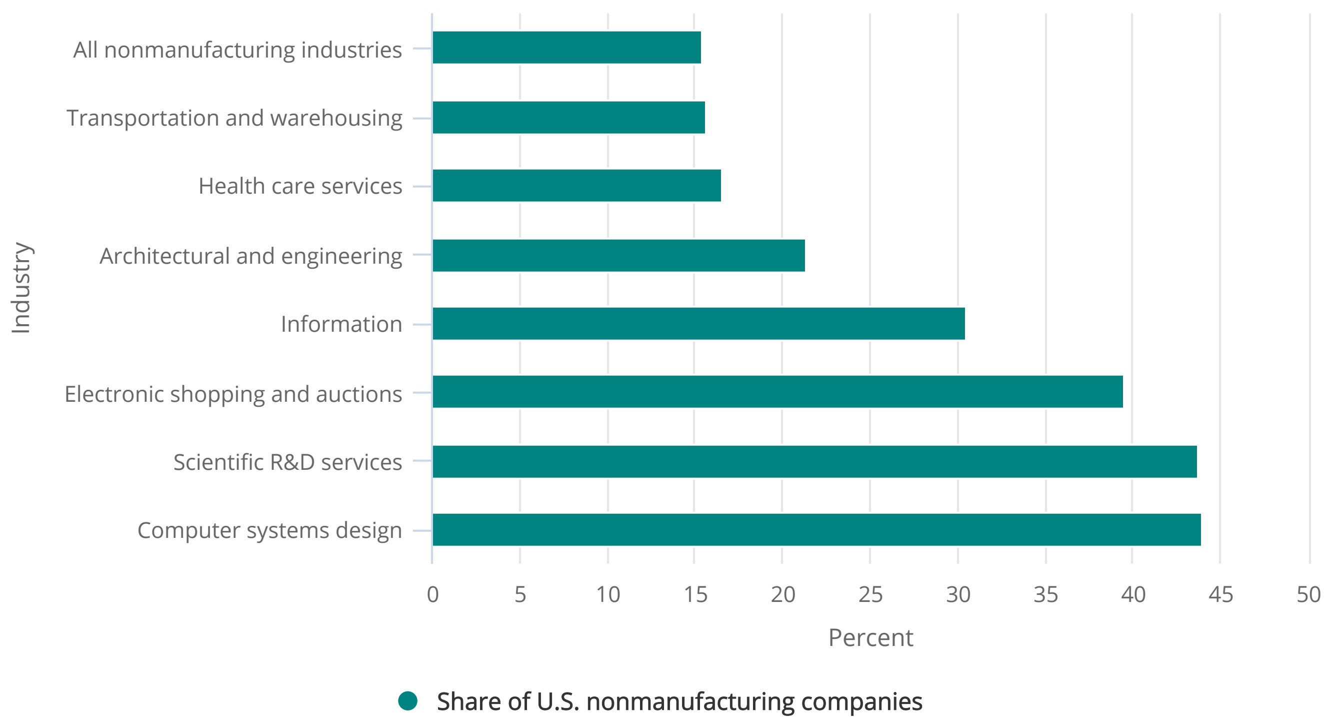
FIGURE 8-27

Share of U.S. nonmanufacturing companies reporting product or process innovation, by selected industry: 2013–15



Note(s)

The survey asked companies to identify innovations introduced from 2013 to 2015. Architectural and engineering category and Computer system design includes related services.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, Business R&D and Innovation Survey (BRDIS) (2015), Table 68.

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Overall, one-third of manufacturing firms reported an innovation, accounting for more than 37,000 firms with innovations. Firms in paper (34%), plastics and rubber (38%), and petroleum and coal products (38%) report innovation rates above one third. For chemicals, transportation equipment, and miscellaneous manufacturing, the industry innovation incidence rates are higher yet—more than 40%.

Outside of manufacturing, 15% of firms, or 200,000 firms, reported innovations. In addition to the ICT-producing industries discussed earlier, transportation and warehousing, health care services, electronic shopping and auctions, and scientific R&D services, among others, have incidence rates above the nonmanufacturing average (Figure 8-27).

Focusing on product innovation compared with process innovation, manufacturing firms overall report product and process innovations at similar rates, about one-quarter of firms. For nonmanufacturing firms, these rates are about 1 in 10. Across industries, U.S. firms reported higher rates of process innovation compared to product innovation (Table 8-10).

TABLE 8-10

U.S. companies introducing new or significantly improved products or processes, by industry sector and industry proportions: 2013–15

(Number and percent)

Industry	NAICS code	New or significantly improved products or processes		New or significantly improved product (goods or services)				New or significantly improved processes				
		Companies (number)[a]	Percent	Companies (number)[a]	Any good or service	Goods	Services	Companies (number)[b]	Any processes	Manufacturing or production methods	Logistics, delivery, or distribution methods	Support activities
					Percent	Percent	Percent		Percent	Percent	Percent	Percent
All industries	21–23, 31–33, 42–81	1,413,932	16.8	1,406,937	10.4	6.4	7.7	1,396,470	12.4	5.1	4.3	9.7
Manufacturing industries	31–33	112,782	33.1	112,249	24.3	21.7	11.4	111,990	24.7	18.4	7.5	14.5
Nonmanufacturing industries	21–23, 42–81	1,301,150	15.4	1,294,688	9.2	5.0	7.4	1,284,480	11.3	4.0	4.1	9.3

[a] Statistics for the number of companies are based only on companies in the United States responding either "Yes" to at least one of the items on the survey relating to new or significantly improved products regardless of whether the company performed or funded R&D. These statistics do not include an adjustment to the weight to account for unit nonresponse.

[b] Statistics for the number of companies are based only on companies in the United States that reported data for at least one of the items on the survey relating to new or significantly improved products or processes, regardless of whether the company performed or funded R&D. These statistics do not include an adjustment to the weight to account for unit nonresponse.

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, and U.S. Census Bureau, Business R&D and Innovation Survey (BRDIS), 2015, Table 68 and Table 69.

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International Comparisons in Innovation Incidence

Interest in international competitiveness drives cross-country comparisons of business innovation rates, and these indicators provide a uniquely focused measure of activity distinct from R&D.

The data described as follows are collected under *The Oslo Manual* (OECD/Eurostat 2005), discussed in the sidebar Concepts and Definitions for Business Innovation Survey Data. While differences in survey methodologies across countries continue to drive inconsistency among international data, broad patterns emerge. Across countries, the highest rates of product and process innovation are reported in relatively smaller, but S&T-focused economies, such as Switzerland, Israel, and Finland. In contrast, Japan, the United Kingdom (UK), and the United States all rank relatively low in reported incidence (Table 8-11).

Not surprisingly, country-level data show innovation incidence varies across firm size. Firms with 250 or more employees had higher innovation rates than smaller firms, with a notable exception. For Australia, small firms had a higher product innovation rate compared with larger firms.

TABLE 8-11

International comparison of innovation rate, product, and process, by country and firm size: 2012–14

(Percent of firms)

Country	Total	Fewer than 250 employees	250 employees or more
Product innovative firms (regardless of any other type of innovation)			
Switzerland	42.4	41.4	68.9
Israel	36.2	35.2	53.3
Ireland	35.7	34.3	66.1
Australia	35.7	35.8	31.1
Finland	34.5	33.2	64.6
Germany	34.4	33.0	62.8
Norway	32.9	32.3	48.4
Netherlands	32.5	31.8	49.8
Belgium	31.9	30.8	56.1
Sweden	31.4	30.4	58.3
Austria	30.8	28.9	69.0
Luxembourg	28.8	27.5	56.6
Portugal	28.4	27.5	64.3
France	27.7	26.2	59.0
United Kingdom	26.8	26.4	36.1
Slovenia	25.2	23.7	61.6
Czech Republic	25.1	23.4	55.9
Italy	24.7	24.0	58.3
Greece	23.4	22.8	65.6
Denmark	23.2	22.2	47.4
Turkey	22.7	22.1	36.5
Lithuania	20.9	19.9	54.5
China	18.7	NA	NA

Country	Total	Fewer than 250 employees	250 employees or more
Brazil	18.5	17.6	43.6
United States	18.4	NA	NA
New Zealand	18.1	17.8	38.1
South Korea	16.8	16.3	34.1
Japan	14.6	13.8	31.6
Slovak Republic	12.6	11.3	35.8
Hungary	12.0	11.1	32.1
Spain	11.2	10.3	43.9
Estonia	11.0	10.2	38.3
Poland	9.5	8.4	38.8
Latvia	8.5	7.7	35.4
Russian Federation	5.3	2.6	15.7
Chile	5.1	4.8	10.1
Process innovative firms (regardless of any other type of innovation)			
Belgium	38.8	37.8	62.9
Ireland	37.8	36.4	67.4
Portugal	35.4	34.6	67.8
Israel	34.0	31.9	71.1
Austria	32.8	30.9	70.1
Brazil	32.1	31.4	53.4
Finland	32.0	31.0	55.0
Lithuania	31.4	30.1	71.9
Australia	31.0	30.8	37.0
Greece	29.6	29.0	66.0
Netherlands	28.1	27.5	42.7
France	27.1	25.9	53.3
Norway	26.9	26.1	45.0

Country	Total	Fewer than 250 employees	250 employees or more
Turkey	26.8	26.2	42.9
Switzerland	26.1	25.0	53.9
Sweden	25.8	24.8	52.1
Luxembourg	25.7	24.7	44.6
Italy	24.5	23.8	58.3
Germany	24.1	22.3	60.5
Denmark	23.2	22.1	48.4
Slovenia	22.6	NA	NA
Czech Republic	22.4	20.5	56.3
China	20.0	NA	NA
United States	19.8	NA	NA
Japan	19.2	18.5	33.3
New Zealand	18.9	18.6	39.2
United Kingdom	17.9	17.6	25.9
South Korea	17.3	16.5	48.9
Spain	14.8	13.9	49.9
Estonia	13.0	12.1	43.9
Slovak Republic	12.9	11.7	34.8
Poland	10.9	9.7	42.6
Latvia	9.7	8.8	41.0
Hungary	9.6	8.7	30.2
Chile	8.2	7.5	18.8

NA = not available.

Note(s)

Where indicated, most recent data are used. Comparison is for North American Industry Classification System equivalents of International Standard Industrial Classification of All Economic Activities Revision 4 sectors and industries in the European Union Core Coverage: B (mining and quarrying); C (manufacturing); D and E (electricity, gas, steam, water supply, sewerage, waste management, remediation); G 46 (wholesale trade, except motor vehicles and motorcycles); H (transport and storage); J 58 (publishing); J 61 (telecommunications); J 62 (computer programming, consultancy, and related activities); J 63 (information services); K (finance and insurance); M 71 (architecture, engineering, technical testing and analysis).

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, and U.S. Census Bureau, Business R&D and Innovation Survey (BRDIS), 2015; Organisation for Economic Co-operation and Development (OECD), OECD Science, Technology and Industry Scoreboard 2015 (2015), https://www.oecd.org/sti/scoreboard.htm.

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Measurement and Data Challenges

Cross-national comparability complicate interpretation of the OECD innovation data. The subjective element in respondent identification of something “new or significantly improved” can vary systematically across countries, and may miss incremental improvements. Also, U.S. survey data identify only new or significantly improved products and processes, whereas Community Innovation Survey data include separate categories for organizational innovation and marketing innovation. Industry and firm size coverage also varies across countries for the surveys.

Statistical agencies have primarily focused their attention on business-sector activity. However, inventors and entrepreneurs have long played an important role in innovation. Individual innovators invent, implement, and share innovations, whether as a tool or as a hobby. Both kinds of activities generally fall outside the scope of business innovation surveys.[6]

Less well understood than business innovation, improvements in collaborative tools and Internet connectivity increase the importance of individual innovators (Gault and von Hippel 2009). Academic researchers in the United States, the UK, Japan, Finland, and South Korea gathered information on free innovation by households between 2012 and 2015, focusing on new product development and modifications (von Hippel 2017). Although relatively small scale (fewer than 2,000 respondents for the United States and the UK each), these surveys find household innovation rates between 1.5% for South Korea and 6.1% for the UK.[7]

Although this activity is less well understood than business innovation, improvements in collaborative tools and Internet connectivity increase this activity’s importance (Gault and von Hippel 2009). A design, computer program, or set of instructions, for example, can be shared for free through the Internet, allowing free reuse throughout the world. Teams of connected contributors add to potential impact.

Productivity Growth and Multifactor Productivity

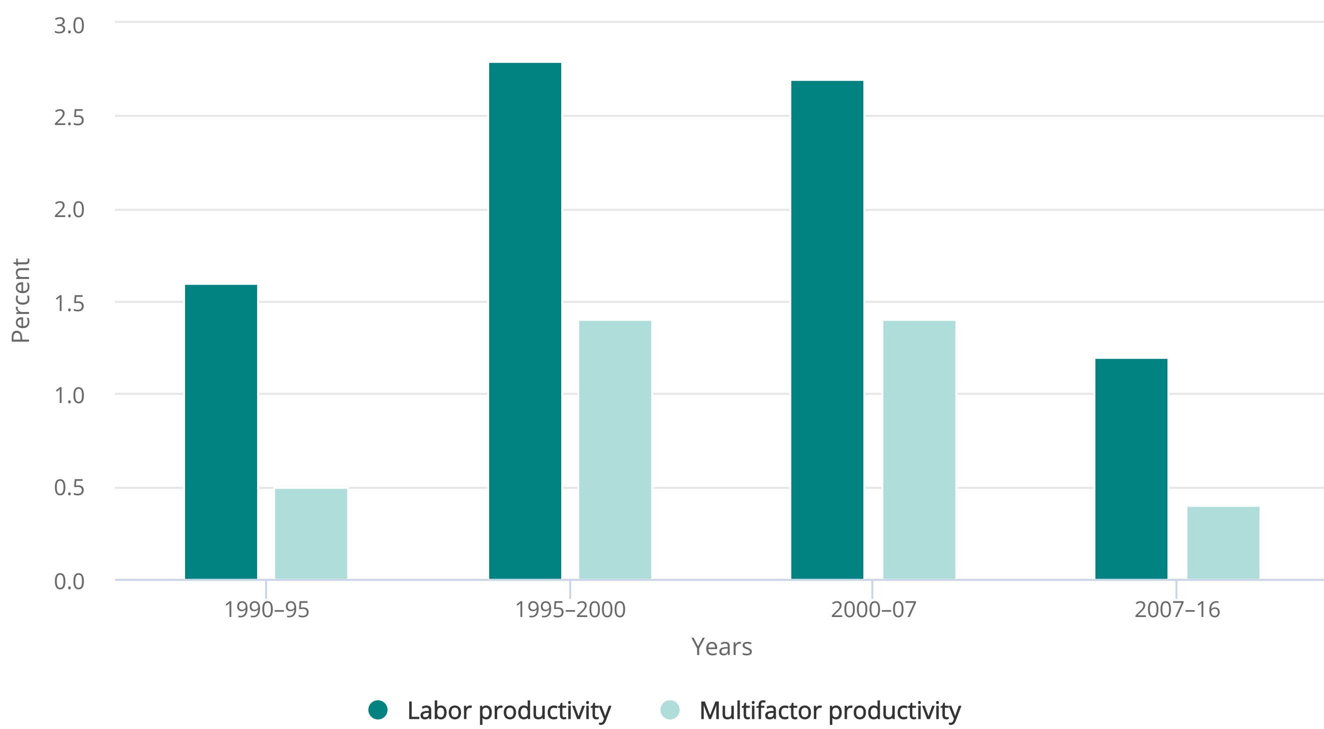
Innovations contribute to economic growth through cost savings from new and improved processes and from sales from new products. New knowledge about the innovation also spreads through the economy. New firms enter and competitive forces can shift the composition of output to higher-productivity firms. If this impact is sufficiently large, we might expect to see rising growth in the ratio of quantity of goods and services produced by workers (GDP) relative to hours worked, measured as labor productivity. Figure 8-28 shows U.S. labor productivity averages for four subperiods between 1990 and

2016. Overall, productivity growth in the United States has been on a declining trend since the early 2000s, including during the economic recovery after the Great Recession (Figure 8-28).

Many factors in addition to the impact of innovation contribute to productivity, including workforce skill and investments in physical and intangible capital. As an indicator of the impact of innovation on economic growth, productivity can be decomposed into component parts, where multifactor productivity is the part attributed to technology's overall impact on the economy. It is calculated as the output growth that cannot be attributed to labor and capital inputs, after accounting for changes in workforce skill and the quality of capital. Figure 8-28 shows that trends in MFP in the United States have been similar to trends in labor productivity: MFP grew faster on average between 1995 and 2007 compared with the first half of the 1990s, and growth moderated since 2007.

FIGURE 8-28

Labor and multifactor productivity annual growth, multiyear averages, private nonfarm business sector: 1990–2016



Note(s)

Growth is calculated by the Bureau of Labor Statistics (BLS) as the average annual rate of growth between the first year and the last year of each period.

Source(s)

BLS, Productivity Measures (2017), Private Non-Farm Business Sector (Excluding Government Enterprises), 30 March 2017 release, accessed 17 June 2017.

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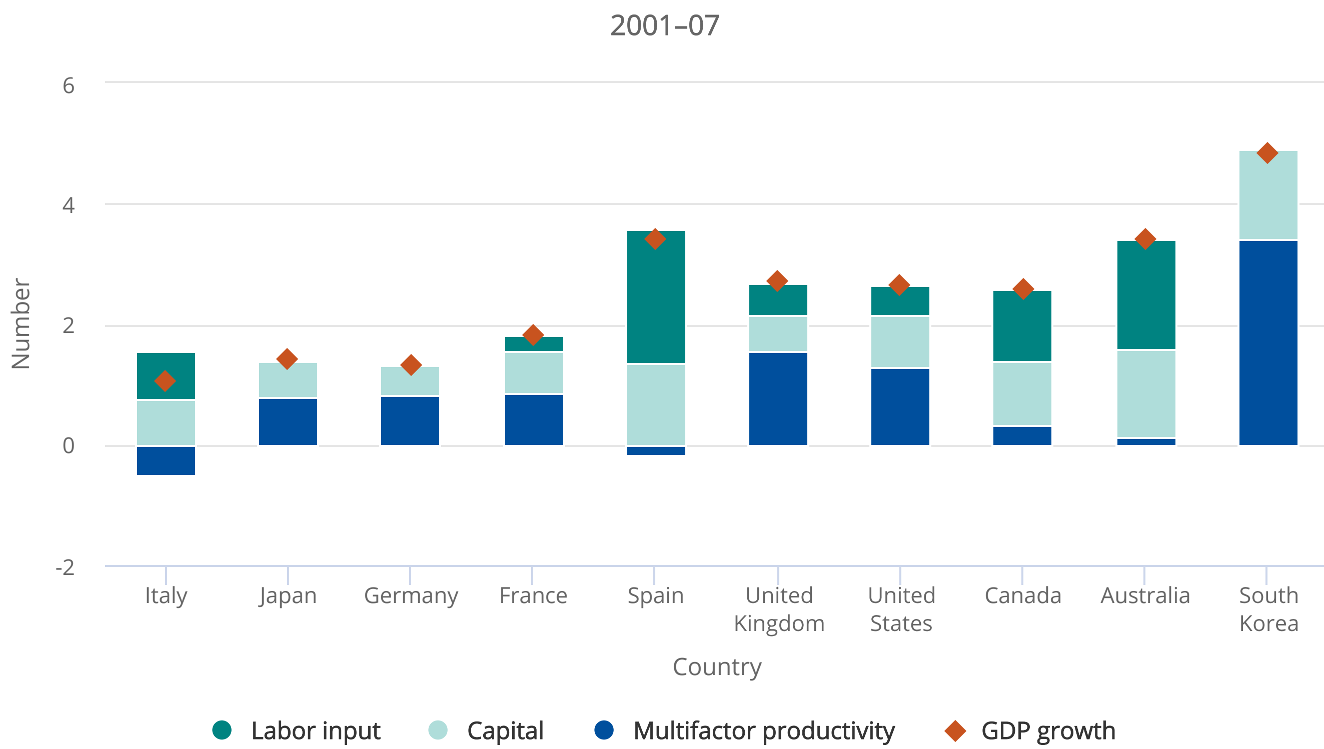
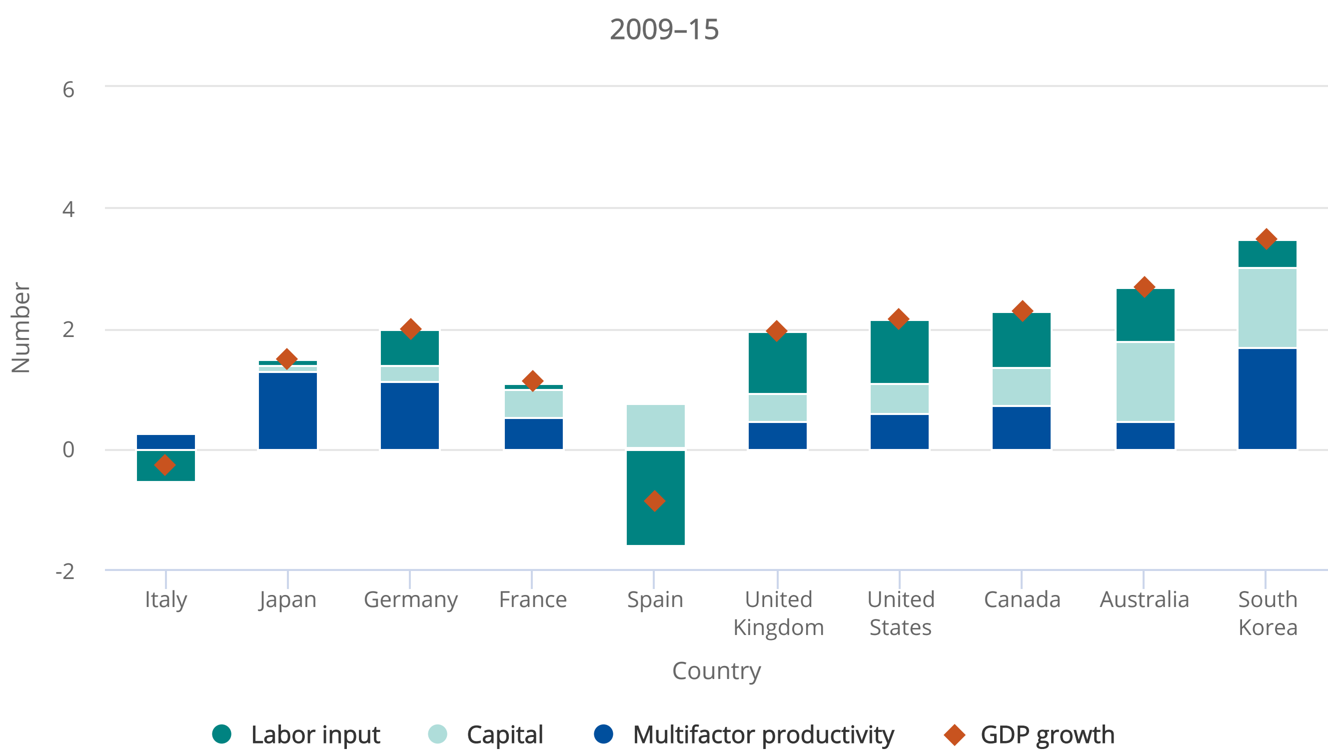
The moderation in the growth rate of MFP is evident in other developed economies as well, including France, Great Britain, and South Korea (OECD 2017). Figure 8-29 shows MFP and GDP growth for the 10 largest OECD countries for two periods: 2001 to 2007 and 2009 to 2015. For each country, the height of each bar is GDP growth. In addition to MFP, increases in labor and increases in capital used in the economy contribute to growth. The factors are shown in Figure 8-29 within each bar: labor input, capital input, and MFP. Only Germany had more than a nominal increase in overall productivity growth across these periods. For Germany, increases in labor and MFP contributed to the growth. For Japan, MFP contributions to growth offset smaller contributions from capital.

FIGURE 8-29

Contributions to GDP growth, average: 2001–07 and 2009–15, selected OECD countries





GDP = gross domestic product.

Note(s)

Data for Spain run through 2014.

Source(s)

Organisation for Economic Co-operation and Development (OECD), *OECD Compendium of Productivity Indicators 2017* (2017), http://dx.doi.org/10.1787/pdtvy-2017-en, Table 2.19, accessed 15 June 2017.

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More broadly, MFP growth has been depressed in both developed and developing economies since the global financial crisis of 2008. Lingering effects of the global recession may be responsible. Structural factors remaining from the recession include corporate debt ratios, misallocation of capital within and across sectors, slower ICT investment, and shifting preference toward less risky investments (Adler et al. 2017).

Many explanations for the slowdown focus on the pace of innovation and technology diffusion from ICT investment. Gordon (2016) argues that the period of the late 1990s to mid-2000s was one of unusually rapid growth from the spread of Internet-enabled communications, entertainment, and commerce, and that the future pace of innovation is unlikely to match this period. From this perspective, MFP is in a secular slowdown, with the gains from investment in ICT in the late 20th century having ended, and the major innovations of the late 19th and early 20th centuries were not and are unlikely to be followed by innovations that have as significant an effect on MFP growth.

An alternative explanation is that MFP growth may be delayed by lags between innovation and its systemic diffusion and adoption (Brynjolfsson and McAfee 2014). Historically, such delays have been especially prominent for general purpose technologies (GPTs; see sidebar General Purpose Technologies), a special category of technologies that are widely used, capable of ongoing technical improvement, and enable innovation in application sectors (Bresnahan 2010).[8]

Measurement issues also effect the clarity of MFP as an indicator of the impact of innovation, since MFP is measured as a residual from economic data. High-quality expenditure data on inputs and outputs are necessary, and supplementary measures needed for good measurement are quantity, price, depreciation, and rate-of-return data for capital (Hall and Jaffe 2012).[9]

SIDEBAR

General Purpose Technologies

General Purpose Technologies (GPT) are a special category of technologies that are widely used, capable of ongoing technical improvement and of enabling innovation in application sectors (Bresnahan 2010). Historical examples are steam engines, the factory system, electricity, the chemical engineering discipline, semiconductors, digital technology, and the Internet. When these technologies become widespread, there are complementarities between technical improvement for the GPT and innovations in related application sectors that can lead to sustained economic growth (David 1990).

GPTs highlight the role of network effects, where the value of an input increases with additional users on the network. The U.S. railroad system complemented the invention of the steam engine and networks of roads complemented that invention of the automobile (Gordon 2016). Complementary innovations rise more easily in a standardized network, leading to an important role for standard setting.

A lesson from the history of GPTs is that the diffusion of a new application can take a long time (e.g., from the invention of the steam engine to its influence on economic growth). Factors that influence the speed of diffusion include the skill of the workforce and the capital with which they work. Bresnahan (2010) observes that the combination of the GPTs and their applications is what produces growth.

Small Fast-Growing Firms in the United States

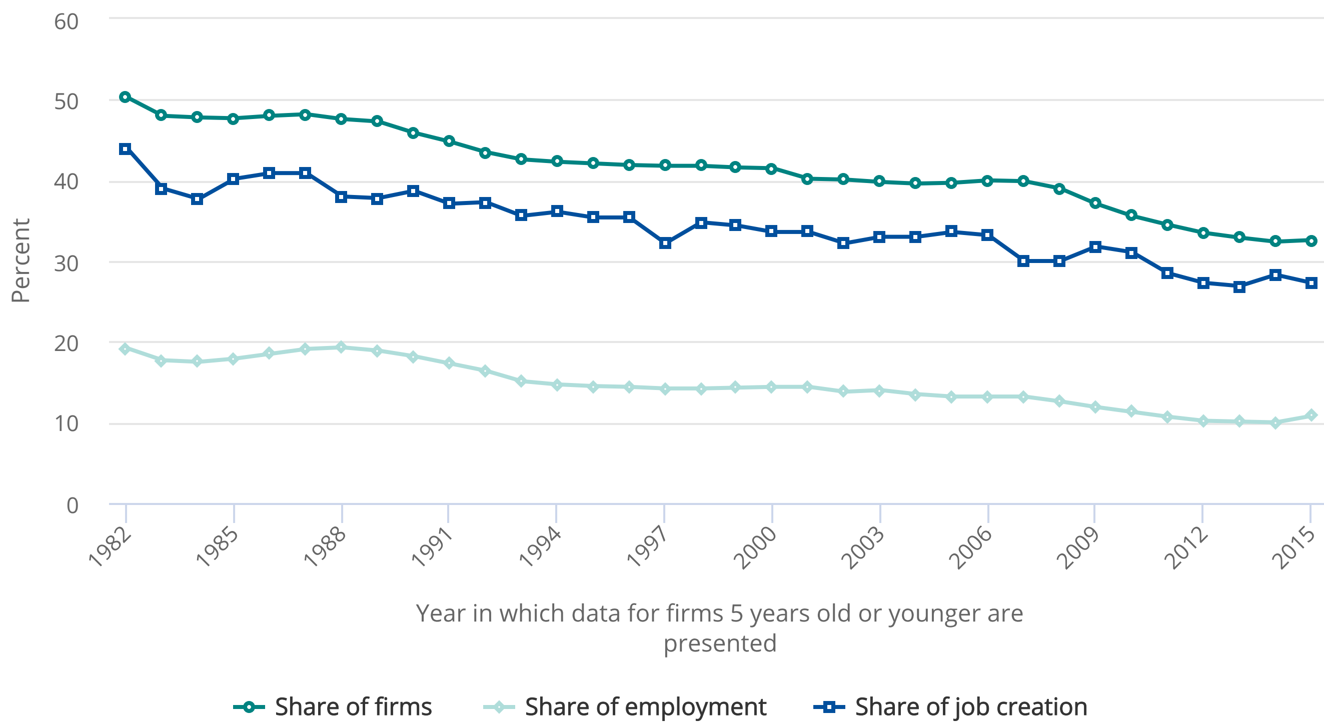
The policy implications for the apparent productivity slowdown are large, motivating better understanding of the causes of the slowdown at the level of individual firms. Changes in firms can be obscured by aggregate sector statistics. The data best suited to explore these dynamics are firm-level data (e.g., those available in the U.S. Census Bureau's Business Dynamics Statistics). These data provide information on establishments opening and closing, firm startups and shutdowns, and their associated employment impacts. The data show that business dynamism, as measured by new startup formation, has been declining in the last decade, leading to fewer firms and older firms (Decker et al. 2014). Importantly, since 2000, the number of high-growth young firms has declined.

Based on U.S. Census data, half of U.S. firms were 5 years old or younger in 1982; this share has steadily declined, reaching 32% in 2014 (Figure 8-30). Along with this decline in the share of young firms, there have been corresponding steady decreases in the share of new job creation and in the share of overall employment from young firms. Young firms accounted for 19% of employment in 1982, and the share declined to 10% by 2014. Although most startups fail and most of the startups that do survive do not grow, a small share of these fast-growing firms makes a disproportionately large contribution to job growth (Decker et al., 2014).

Although the factors behind these trends are not well understood, industry concentration and barriers to entry for inventors and entrepreneurs may be factors contributing to this decrease in dynamism in the U.S. economy. Foster and coauthors (2017) suggest that career paths of entrepreneurs and the activity of new firms are areas in which better data and analysis can help explain how innovation activity affects productivity.

FIGURE 8-30

Share of firms, job creation, and employment from firms 5 years old or younger: 1982–2015



Source(s)

U.S. Census Bureau, Business Dynamics Statistics, http://www.census.gov/ces/dataproducts/bds/data_firm.html; analysis presented in Decker R, Haltiwanger J, Jarmin R, Miranda J, The role of entrepreneurship in U.S. job creation and economic dynamism, *Journal of Economic Perspectives* 28(3):2–24 (2014).

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[1] See Bain & Company (2015) and Fung Global Retail and Technology (2017:4–6) for a discussion of the factors in the spike in venture capital financing.

[2] Another possibility is that the behavior of venture capital investors changed because fewer opportunities for attractive risky investments were available in the 2000s than in the 1990s.

[3] Source: PitchBook, http://pitchbook.com/.

[4] Snapchat's share prices rose more than 40% compared with its initial pricing on its IPO on 2 March 2017, resulting in a market capitalization of $33 billion.

[5] Source: PitchBook, http://pitchbook.com/.

[6] According to von Hippel (2017) , a user-developed innovation has been developed by the firm or the consumer that expects to benefit from using the product or service, rather than by the firm that expects to benefit from selling the product or service. A free innovation is one created outside of paid work time and not protected against sharing.

[7] The rate for the U.S. sample was 5.2% (i.e., 1 in 20 had developed an innovation as defined by the survey).

[8] When these technologies become widespread, there are complementarities between technical improvement for the GPTs and innovations in related application sectors that can lead to sustained aggregate economic growth. These gains, however, can take considerable time to emerge and may require significant and costly co-investments. From this perspective, the long process of diffusion of digitally networked GPTs has depressed the MFP growth rate in the near term but can increase it in the future.

[9] Branstetter and Sichel (2017) argue that improved measurement of prices for IT products would show multifactor productivity growing more quickly than in official statistics. The topic is not yet settled, including alternate estimates of productivity growth with adjustments for potential mismeasurement. Byrne, Fernald, and Reinsdorf (2016) adjust experimental growth measures for many of the identified issues and find that these adjustments would, overall, make the productivity slowdown worse instead of better.

Conclusion

This chapter focuses on the creation of inventions, knowledge transfer, and innovation through the introduction of new and improved goods and services. Many indicators in earlier chapters focus on S&E fields that flow into basic research and innovation.

Taken as a whole, *Indicators* chapters show a dynamic system, with global players large and small. Knowledge creation through skilled and trained workers, producing research discoveries and new technologies, fuel a fast-changing, knowledge-intensive global economy. Throughout, *Indicators* provides insights into inputs and activities of the U.S. innovation system in relation to the rest of the world. These topics include the development of human capital in S&E (Chapter 1, Chapter 2, and Chapter 3), R&D expenditures (Chapter 4 and Chapter 5), peer-reviewed research activities (Chapter 5), trade in knowledge-intensive industries (Chapter 6), and public perception of science (Chapter 7). The State Indicators data tool provides state-level indicators for many of these topics.

This chapter's indicators address invention, knowledge transfer, and innovation with high-quality data from a variety of sources, tracing through technology areas, industries, and product markets. While informative together, none provide a completely satisfactory innovation indicator alone. A key insight of this chapter is that a multiple-framework approach, when applied to complex and disparate data, can yield valuable insights into where and how innovation is taking place.

Looking forward, four main data challenges in the innovation system are (1) indicator coverage for all sectors of the economy, including households and entrepreneurs, government, and nonprofit institutions; (2) indicators of invention for unpatented inventions; (3) time series or other linked data to trace activities across time and geography, and finally, (4) indicators focused on impact and outcome measures for policy use.

Glossary

Definitions

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

Federally funded research and development center (FFRDC): R&D-performing organizations that are exclusively or substantially financed by the federal government, to meet a particular R&D objective or, in some instances, to provide major facilities at universities for research and associated training purposes. Each FFRDC is administered by an industrial firm, a university, or a nonprofit institution.

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

Intangibles: Nonphysical factors that contribute to or are used to produce goods or services, or are intended to generate future benefits to the entities that control their use (Blair and Wallman 2001).

Mask works:A series of related images used as patterns in the construction of semiconductor chips.

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

Technology transfer: The process by which technology or knowledge developed in one place or for one purpose is applied and exploited in another place for some other purpose. In the federal setting, technology transfer is the process by which existing knowledge, facilities, or capabilities developed under federal R&D funding are used to fulfill public and private needs.

Key to Acronyms and Abbreviations

ACS: American Competitiveness Survey

AFFOA: Advanced Functional Fabrics of America

ARM: Advanced Robotics for Manufacturing

ARMI: Advanced Regenerative Manufacturing Institute

ARPA-E: Advanced Research Projects Agency–Energy

AUTM: Association of University Technology Managers

BEA: Bureau of Economic Analysis

BLS: Bureau of Labor Statistics

BRDIS: Business R&D and Innovation Survey

CEMI: Clean Energy Manufacturing Initiative

CIS: Community Innovation Survey

CRADA: cooperative R&D agreement

DHS: Department of Homeland Security

DMDII: Digital Manufacturing and Design Innovation Institute

DOC: Department of Commerce

DOD: Department of Defense

DOE: Department of Energy

ED: Department of Education

EU: European Union

FFRDC: federally funded research and development center

FLC: Federal Laboratory Consortium for Technology Transfer

FY: fiscal year

GDP: gross domestic product

GPT: general purpose technology

HHS: Department of Health and Human Services

IACMI: Institute for Advanced Composites Manufacturing Innovation

ICT: information and communications technologies

IPC: International Patent Classification

IPO: initial public offering

ISO: International Organization for Standardization

IT: information technology

IUCRC: Industry-University Cooperative Research Centers Program

LIFT: Lightweight Innovations for Tomorrow

MEP: Hollings Manufacturing Extension Partnership

MFP: multifactor productivity

NAICS: North American Industry Classification System

NASA: National Aeronautics and Space Administration

NIIMBL: National Institute for Innovation in Manufacturing Biopharmaceuticals

NIST: National Institute of Standards and Technology

NPL: nonpatent literature

NSF: National Science Foundation

OECD: Organisation for Economic Co-operation and Development

R&D: research and development

RAPID: Rapid Advancement in Process Intensification Deployment

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

ROW: rest of world

S&E: science and engineering

S&T: science and technology

SBA: U.S. Small Business Administration

SBIR: Small Business Innovation Research

SEP: standard essential patent

STTR: Small Business Technology Transfer

TFP: total factor productivity

UK: United Kingdom

USDA: Department of Agriculture

USPTO: U.S. Patent and Trademark Office

WIPO: World Intellectual Property Organization

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