CHAPTER 5

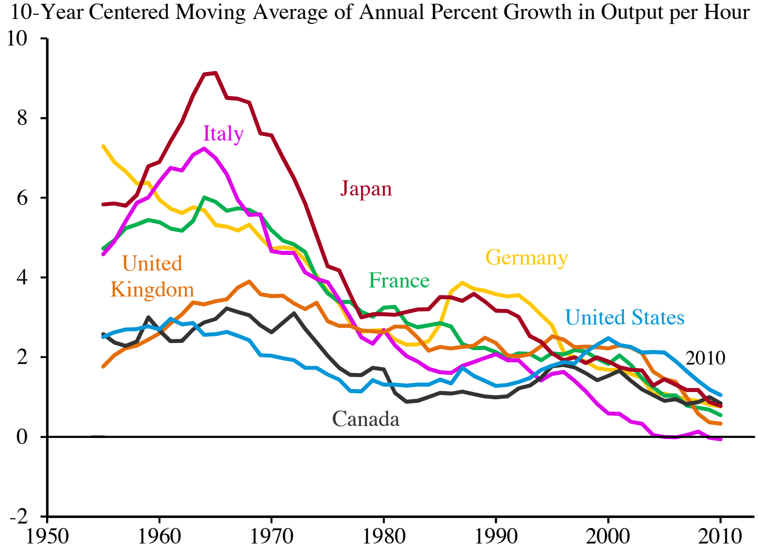
TECHNOLOGY AND INNOVATION

Productivity growth is critical to the well-being of the American economy, its workers, and its households. Growth in labor productivity means American workers generate more output for a given amount of work, which can lead to higher living standards via higher wages, lower prices, and a greater variety of products.[1] Labor productivity growth in the United States has come down from its highs in the middle of the 20th century (see Figure 5-1), though less dramatically than in other advanced economies that had experienced a surge in productivity in the immediate aftermath of the second World War. Between 1990 and 2000, U.S. labor productivity growth rebounded. However, over the last decade, even though the United States has led other advanced countries in labor productivity growth, achieving robust measured productivity growth has been a substantial challenge.[2]

Labor productivity growth—measured as output per hour—comes from three primary sources: increases in capital, improvements in the quality of labor, and "total factor productivity" (TFP, or what the U.S. Bureau of Labor Statistics formally refers to as multifactor productivity). The first source—the accumulation of physical capital—fuels productivity growth through investments in machines, tools, computers, factories, infrastructure, and other items that are used to produce new output. The second source, labor quality upgrades, comes from greater education and training of the workers who operate these machines, tools and computers, as well as manage factories and infrastructure, to produce output. Rapid increases in capital accumulation or educational attainment can increase the output per hour of an economy and potentially improve living standards. There are, however, generally limits to the extent of productivity gains that can result

[1] The 2010 Economic Report of the President, specifically Chapter 10, entitled "Fostering Productivity Growth through Innovation and Trade," covers this point in further detail.
[2] It is possible that some of the recent decline in productivity growth is due to measurement issues because official estimates do not count "free" online media and open-source software. Box 2-5 in Chapter 2 discusses these issues in more detail.

Figure 5-1
Labor Productivity Growth, 1955–2010



Source: Conference Board, Total Economy Database; CEA calculations.

from simply piling more resources (physical or human capital) into the production process.

The most important source of productivity growth overall is the third factor—total factor productivity. TFP can be thought of as the way that labor and capital come together to produce output. For example, imagine taking the same workers and the same equipment and changing the way that the workers use the equipment to get more output. Over one-half of the growth in productivity between 1948 and 2014 came from exactly such changes. Variations in TFP also explain most of the variations in productivity growth over longer periods, as the contributions of capital and labor quality have been roughly constant over time. More recently, however, the contribution from capital has decreased significantly.[3]

When TFP increases, a country experiences higher levels of output even when both the returns to, and the amount used of, capital and labor remain constant. Such TFP improvements happen when innovators, entrepreneurs, and managers create new products or make improvements to existing products, often in response to market incentives. This improvement might happen, for example, if a firm reorganizes the layout of its factory in a new way so that production lines run more smoothly. Or it might happen

[3] For more detail, see pages 7 to 9 of Chairman Jason Furman's July 9, 2015 speech entitled "Productivity Growth in the Advanced Economics: The Past, the Present, and Lessons for the Future."

if an inventor uncovers a new method for producing the same output at a lower cost. Either way, it should be noted that these types of innovations typically require significant effort and resources.

Sometimes these innovations can be relatively incremental, such as waste-reducing technology that improves soccer-ball production in Pakistan (Atkin et al. 2015), or management practices that improve quality and reduce inventory in Indian textile plants (Bloom et al. 2013). Even though each one is small, many such incremental innovations can lead to substantial aggregate TFP growth. A recent paper by Garcia-Macia, Hsieh, and Klenow (2015) estimates that much of the aggregate TFP growth in the U.S. manufacturing sector from 1992 to 2002 came from incremental innovations, such as product improvements, rather than the creation of entirely new products. Other times, innovations can have such profound effects on productivity growth, as was the case with steam and electricity, that their adoption becomes all but imperative for a firm. In such cases, the innovation approaches the status of a de facto industry standard. Whether incremental or transformative, technologies and innovations are critical to ensuring that the United States maintains and expands on its recent growth.

Competition from new and existing firms plays an important role in fostering this growth. Startups are a critical pathway for the commercialization of innovative new ideas and products. Startups, or the possibility of entry by a startup, also create incentives for established firms to innovate and reduce costs, which in turn drives growth. However, these productivity-enhancing channels may be weakening as the rate of new firm formation has been in persistent decline since the 1970s, as have various measures of worker mobility and job turnover. The share of patenting by new firms has also been in decline. At the same time, there are signs of increasing concentration across multiple industries. These trends point to the importance of removing barriers to entry for inventors and entrepreneurs.

This chapter describes the state of technology and innovation in the United States, including recent trends, challenges, and opportunities. The chapter begins by reviewing the recent trajectory of the rate of business dynamism and labor market dynamism. It then reviews trends in research and development (R&D) spending and patenting. Finally, it describes in detail two promising areas that can help the United States to boost TFP growth in the future—robotics and digital communications technology—as well as potential challenges posed by these innovations.

Competition and Dynamism Play a Critical Role

More than 50 years ago, the Nobel Prize-winning economist Kenneth Arrow (1962) argued that a monopolist may have relatively weak incentives to innovate since its innovations do not allow it to “steal” business from competitors. Competition pushes firms to invest in new technologies that help to lower costs and also to invest in innovations that can lead to quality improvements of existing products.[4] Competition can arise in multiple ways. An incumbent firm can face competition from other incumbents within the same market that have come up with a new way to produce a good or service or that have invented a new product that siphons off existing customers. Or, competition can come from firms new to the market, which include both startups and established firms. Entry can occur by established firms in a different product market in the same geography, as happened when “black cars” (that is, limousine and town car services) entered the taxi industry in many U.S. cities, or it could involve a firm in a similar product market but from a different geographic location (Rawley 2010). The latter case is often what happens with both domestic and international trade (see Box 5-1 on Trade).

The Role of Startups

Startups are vital to productivity growth in the United States. Startups are often the way in which a new product or service is first brought to market. A case in point is the small company that Bill Hewlett and Dave Packard founded in a garage in Palo Alto in 1939, which commercialized an early version of an electronic oscillator, a vital component in electronic devices. Hewlett and Packard’s inventions, along with those of multiple other electronics inventors, helped spur the information technology-fueled productivity rebound in the mid-1990s, which saw average labor productivity growth jump more than a percentage point to 2.4 percent a year (Jorgenson and Stiroh 2000; Oliner and Sichel 2002).

Academic research finds that entrepreneurship can lead to long-run productivity growth (e.g., King and Levine 1993), much in the same way that Hewlett and Packard’s entrepreneurial vision ultimately led to productivity gains decades after they founded their company. Notably, though personal computers were becoming widespread in the 1980s and 1990s, there was a lag until these innovations translated into a meaningful uptick in productivity

[4] As noted by many researchers, while some competition is better than none when it comes to stimulating innovation, there is evidence that too much competition can be detrimental. This so called inverted-U shape of the relationship between competition and innovation has been observed across multiple industries (Aghion et al. 2005).

Box 5-1: Trade

Domestic and international trade are of critical importance to the economy overall but also to innovation. Trade promotes innovation and associated productivity growth in two ways: 1) by increasing the efficiency of the innovation process, thus helping bring more innovations to market, faster and at lower prices; and 2) by increasing the rewards that an innovator realizes when his or her new idea succeeds.

Domestic trade—measured by commodity flows between geographies in the United States—is an important driver of U.S. gross domestic product (GDP) and productivity growth. Infrastructure is important to domestic trade because it provides the means by which a firm can efficiently ship its products from one location to another. Chapter 6 of this *Report* covers the preconditions for, and consequences of, improving the quality and quantity of U.S. transportation infrastructure in greater detail, as well as how the interstate highway, long-distance freight rail, and air transportation systems are particularly important to productivity. These infrastructure assets also facilitate international trade.

International trade is also an important driver of innovation and productivity growth. In the words of Nobel Prize-winning economist Robert Solow (2007), "[r]elatively free trade has the advantage that the possibility of increasing market share in world markets is a constant incentive for innovative activity." One recent review of the evidence calls the relationship between globalization and productivity growth a "robust finding" (De Loecker and Goldberg 2014).

International trade can drive productivity growth in several ways. When U.S. firms sell abroad, they can sell more products per firm, and this increase in scale may, in some cases, lead to lower costs and higher productivity. International trade allows companies to access a larger market, which results in greater revenues and potentially higher profits for a given level of innovation, and therefore raises the incentive to innovate. For example, recent economic research by Aw, Roberts, and Xu (2008) finds that firms with experience in foreign markets have a greater probability of R&D investment. Trade can also generate a positive effect on aggregate productivity through reallocation. When firms are able to grow and expand to meet demand from consumers in other countries, these firms become a larger part of the economy and employ a larger share of workers. Hence, the reallocation of labor and production toward more productive firms as they expand after trade liberalization generates higher aggregate productivity in the economy as a whole (Melitz 2003).

Moreover, trade can expose both exporters and importers to new ideas and novel tools, materials, or techniques that make them more productive. Some of this learning is simply copying, as when a firm adopts pre-existing technology or know-how. At the same time, since roughly one-half of all U.S. imports are inputs into the production process, imports can actually reduce firms' costs by making a greater variety of goods available at lower prices, and such growth can lead American businesses to expand production and employment, as highlighted in the academic literature. Romer (1994) shows that a country's gains from international trade are multiplied substantially when the benefits of cheaper, more varied imported inputs and commodities are taken into account. Halpern, Koren, and Szeidl (2015) also find that access to a wider variety of imported inputs following trade liberalization increases firm productivity. Amiti and Wei (2009) find that imports of service inputs had a significant positive effect on manufacturing productivity in the United States between 1992 and 2000. A recent paper by Boler, Moxnes, and Ulltveit-Moe (2015) demonstrates that improved access to imported inputs promotes R&D investment and thus technological innovation.

Finally, trade can also increase competition, which can spur innovation and productivity growth. Sutton (2012) argues that one of the pathways through which developed economies benefit from international trade is that entry by competitors at the low end of the productivity distribution induces innovation in firms at the high end of the productivity distribution. Aghion et al. (2004) studied U.K. firms from 1980 to 1993 and also found large gains in TFP for incumbent firms, in response to entry by foreign competitors.

The Trans-Pacific Partnership (TPP), the trade agreement between the United States and 11 other Pacific Rim countries, opens the world's fastest-growing markets to U.S. goods and services. The expanded opportunities for trade created by the TPP will help the most productive U.S. firms expand, make other U.S. firms more productive, and drive innovation and, ultimately, American productivity. Similarly, the Transatlantic Trade and Investment Partnership (T-TIP), a trade agreement currently under negotiation between the United States and European Union, will help further drive innovation and productivity.

growth. Research also tells us that institutions that protect property rights, that ensure the availability of affordable credit from healthy financial intermediaries, and that promote the rule of law have historically been important ingredients for fostering private-sector economic activity and entrepreneurial success (Acemoglu, Johnson, and Robinson 2005; North and Weingast 1989). Entrepreneurial success ultimately translates into improvements in quality of life and in productivity growth (King and Levine 1993).

In addition to commercializing new technologies, startups provide jobs. In 2013, startups accounted for over 2 million new jobs compared with established firms that accounted for over 8 million new jobs.[5] However, as discussed below, the birth rate of startups has been declining over time (see Figure 5-3). While many startups fail, those that remain in business tend to grow, creating demand for new jobs. Thus, a healthy environment for startups sets the stage for current and future job growth.

Most startups rely on a mix of debt and equity financing (Robb and Robinson 2014), meaning that a healthy, competitive financial system is vital to ensuring that startups can find the financing they need. Venture capital investments, both in number of deals and in dollars, provide two indicators of the health of financial markets for new firms. While such investments continue to lag historical highs from the dot-com boom, these indicators have improved greatly since the financial crisis in 2008 (see Figure 5-2). Average quarterly venture capital investment dollars (scaled by GDP) in 2015 were at a level not seen since 2001, indicating that access to capital for entrepreneurs and inventors is improving, though capital for innovative startups remains predominantly available in certain geographies, making high-growth business creation a challenge outside of a handful of metro hubs.

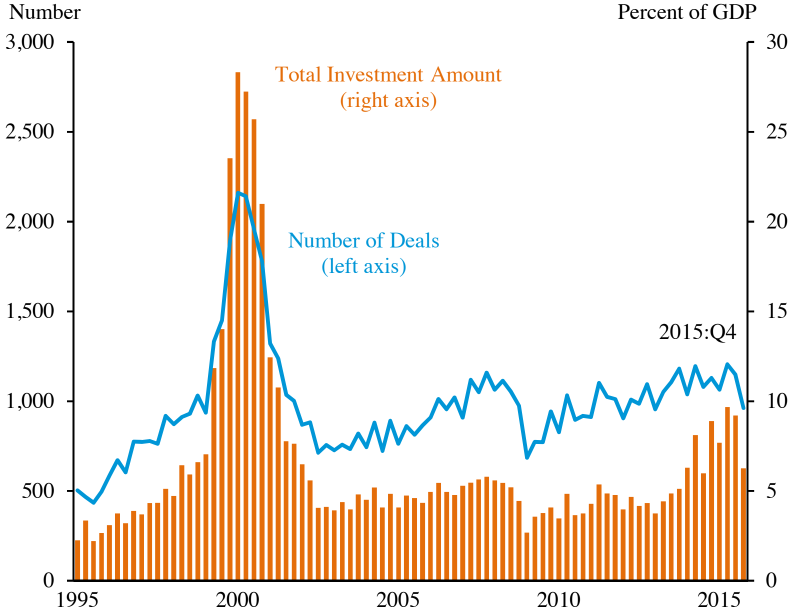
Not only do startups help to commercialize many innovative new ideas, but also startups—or even the threat of entry by a startup—help to motivate established businesses to innovate continuously to improve their existing products (Seamans 2012). This result suggests that an important function of startups is not only to innovate and commercialize new products, but also to push established firms to do so as well. In fact, there do not need to be many startups that actively enter into an industry before the incumbent firms in that industry undertake many changes to enhance productivity or improve consumer welfare. For example, Seamans (2012) shows that the mere possibility of entry by a city-owned cable system is enough to induce product upgrades by incumbent cable systems. Thus, this dual role of startups helps to improve consumer welfare and spur innovation and productivity growth.

Declining Business Dynamism

While startups are vital to the commercialization of new ideas and productivity growth, entry by startups has been declining in the United States since the late 1970s. With exit rates relatively constant, this trend means that the average age of U.S. firms is increasing, while the number of firms is declining. Business dynamism—the so-called churn or birth and death rates of firms—has been in persistent decline in the United States since

[5] These data come from the U.S. Census Bureau's Business Dynamics Statistics.

Figure 5-2
Quantity and Volume of Venture Capital Deals, 1995–2015



Source: PWC/NVCA MoneyTree Report; Thomson Reuters.

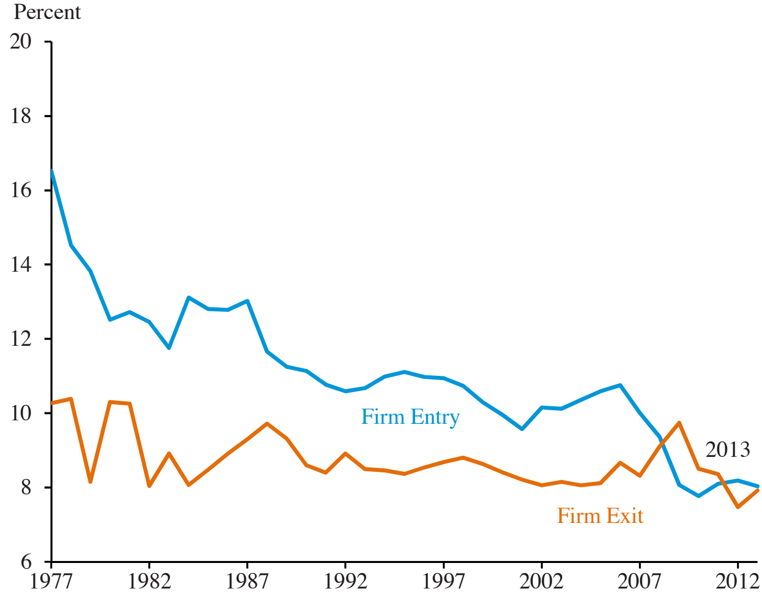
the 1970s (as shown in Figure 5-3). Moreover, whereas in the 1980s and 1990s declining dynamism was observed in selected sectors, notably retail, the decline was observed across all sectors in the 2000s, including the traditionally high-growth information technology sector (Decker et al. 2014).

This trend likely has some relationship to contemporaneous declines in productivity and innovation, though the direction of that relationship is not so clear. A decline in innovation and productivity may be leading to fewer entrants and successful challenges to incumbents, or some exogenous factor—for example, a business environment that limits competition or erects barriers to entry (see Box 5-2 on Occupational Licensing below)—may be driving lower rates of new firm formation that then result in lower levels of innovation. Lower rates of firm entry may be reducing the kind of competition among firms that usually leads them to innovate and improve their efficiency, thus weighing on total factor productivity growth.

The reasons for declining firm entry rates are not well understood, but the trend has been downward for nearly four decades. A partial explanation is that barriers to entry have increased in many industries. For some industries, these barriers could be in the form of occupational licenses (see Box 5-2 on Occupational Licensing). In other cases, these barriers could be in the form of Federal, State, or local licenses or permits. Oftentimes these

Figure 5-3

Firm Entry and Exit Rates in the United States, 1977–2013



Source: U.S. Census Bureau, Business Dynamics Statistics.

licenses and permits are designed to ensure that businesses comply with important consumer safety rules. For example, restaurants in New York City are required to have a manager who has passed a Food Protection Course.[6] Such regulations add fixed costs to an entrepreneur wanting to open a new business but oftentimes serve a valuable role in protecting public well-being.

In other cases, the barriers to entry may be related to various advantages that have accrued to incumbent firms over time. These could be political in nature; for example, existing firms could lobby for rules protecting them from new entrants, as have been seen in the case of the taxi and limousine industry, where Internet-based applications from new entrants have recently begun to disrupt the local ride-for-hire sector. The barriers could also be related to economies of scale, whereby the incumbent has become so large that it has effectively foreclosed on the viability of entry by another firm. Some industries, such as power transmission, water, and other utilities, have natural monopolies, which occur when the fixed costs are very high, and marginal costs are low and approaching zero. Some newer technology markets in which network effects are important, such as social media sites, may come to be dominated by one firm, because the network externalities in these markets tip to one provider of the network good.

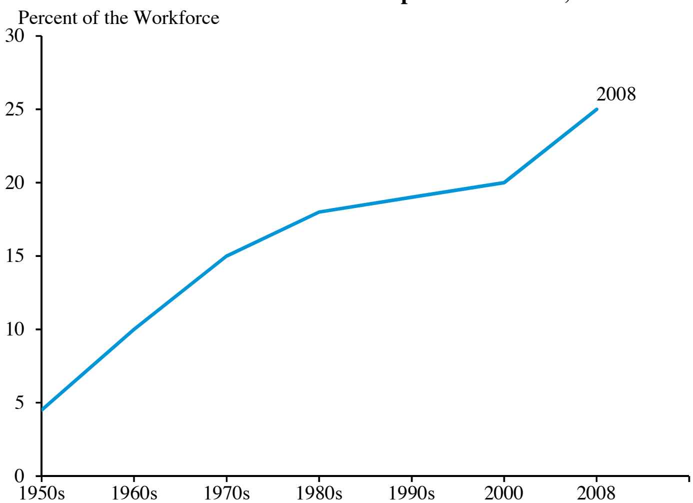
[6] Requirements listed at: https://www1.nyc.gov/nycbusiness/description/food-service-establishment-permit/apply

Box 5-2: Occupational Licensing

One factor that may be contributing to the broad-based decline in the fluidity of the economy in the last several decades, including declining firm entry rates, less worker fluidity, and less job turnover, is the increasing prevalence of occupational licensing rules. This phenomenon can create barriers to entry for firms and workers in a market or geographic location, thus limiting competition and potentially generating other market distortions. Work by Kleiner and Krueger (2013) charting the historical growth in licensing from a number of different data sources shows that the share of the U.S. workforce covered by state licensing laws grew fivefold in the second half of the 20th century, from less than 5 percent in the early 1950s to 25 percent by 2008 (Figure 5-i below). Although state licenses account for the bulk of licensing, the addition of local- and Federal-licensed occupations further raises the share of the workforce that was licensed in 2008 to 29 percent.

While part of this increase in the percent of licensed workers is due to employment growth within certain heavily licensed fields such as health care and education, it is primarily due to an increase in the number of occupations that require a license. Analysis by the Council of Economic Advisers (CEA) finds that roughly two-thirds of the growth in the proportion of workers licensed at the State level from the 1960s to 2008 is attributable to growth in the number of licensed occupations,

Figure 5-i
Share of Workers with a State Occupational License, 1950–2008



Sources: The Council of State Governments (1952); Greene (1969); Kleiner (1990); Kleiner (2006); and Kleiner and Krueger (2013); Westat data; CEA calculations.

while a little over one-third is due to changes in the occupational composition of the workforce (CEA et al. 2015).

When designed and implemented carefully, licensing can offer important health and safety protections to consumers and the public, as well as benefits to workers. However, some occupational licensing regimes can present a classic case of so-called rent-seeking behavior by incumbents, whereby these individuals and firms may successfully lobby government entities to erect entry barriers to would-be competitors that result in higher-than-normal returns to capital and labor. In addition, licensing requirements vary substantially by state—both in terms of which professions require licenses and the requirements for obtaining a license—making it more difficult for workers to move across state lines. Thus, it is possible that the steady increase in the number of licensed workers is contributing to the United States' decades-long decrease in interstate mobility, though it is unlikely that licensing is the main driver of this change (CEA et al. 2015).

Land use regulations and zoning can also make it more difficult for entrepreneurs to start new firms or for workers to move to more productive cities and firms. See Box 2-6 in Chapter 2 for discussion of the effects that result from overly restrictive land use regulations.

Whether a cause or consequence of declining firm entry rates, market concentration appears to have risen over the same time period. The U.S. Census Bureau's data on market consolidation, tabulated in a recent paper by Furman and Orszag (2015), shows a clear trend of consolidation in the nonfarm business sector. The data show that, in three-fourths of the broad sectors for which data are available, the 50 largest firms gained revenue share between 1997 and 2007. Their paper also highlights results from a number of independent studies that have documented increased market concentration across industries including agriculture, upstream agricultural supply, banking, hospitals, and wireless telecommunications.

To the extent that industries look more like oligopolies than perfectly competitive markets, meaning that some firms dominate the market and possess certain advantages, they will generate economic rents (Furman and Orszag 2015). Economic rents are returns to a factor of production, like capital or land, which exceed the level needed to bring that factor into production; in other words, returns in excess of the level expected based on economic fundamentals. Economic rents are split between firms and their workers, but firms with higher market power have greater leverage to retain rents, either by charging high prices or by paying their workers less. In the absence of some countervailing public purpose, such rents reflect a decrease in consumer welfare as they erode the surplus that would otherwise accrue to consumers and workers in a competitive market; for example, through lower prices for goods or higher wages from their employees. Moreover, absent entry or threat of entry by startups, incumbents in these concentrated industries have less incentive to innovate, leading to lower productivity growth in the long run.

Declining Labor Market Dynamism

Business dynamism is directly connected to labor market dynamism (or fluidity or churn), which refers to the frequency of changes in who is working for whom in the labor market—a topic that was covered in detail in Chapter 3 of the 2015 *Economic Report of the President*. From the worker's perspective, fluidity is measured by hires and separations; from the firm's perspective, it is measured by new positions (job creation) and eliminated positions (job destruction) (Council of Economic Advisers 2015a).

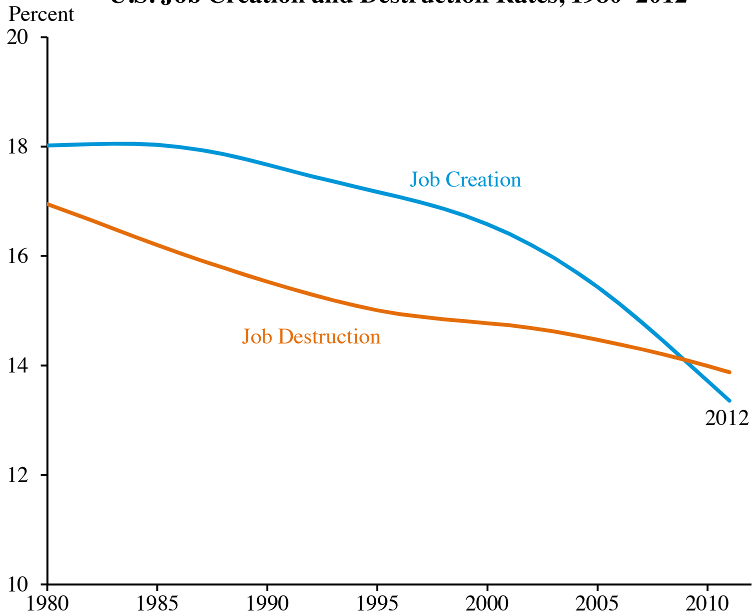
Figure 5-4 illustrates that both job creation and job destruction as a share of total employment have been in continuous decline since 1980 but that job creation has fallen faster in the last two decades. This trend can be explained in part by the decline in business dynamism. There are fewer young firms in the economy today than in the 1980s. Young firms that survive grow faster than older, established firms. Having fewer young firms thus delays recovery after recessions, accounting for part of the reason why job creation has fallen throughout this period. The rate of job destruction has fallen more slowly over the same timeframe in part because older firms are more resilient to macroeconomic shocks and other sudden, adverse events (Decker et al. 2014).

Lower rates of job creation and destruction may be contributing to reduced churn in the labor market and affecting the process by which workers find jobs best matched to their skills and vice versa, lowering overall productivity for all firms—young and old. Workers and firms alike benefit when there is a good match between the worker's skillset and the task required of him or her by the firm. This skillset-job match leads to cost savings, some of which may be passed on to consumers in the form of lower prices, some of which may be enjoyed by the worker in the form of higher wages, and some of which is retained by the firm via higher profits.

Thus, existing firms can increase their productivity by hiring workers with specific know-how or technological skills, or skills that better fit the jobs at a particular firm. The supply of such workers available to meet firms' demand, however, is limited in three ways. Know-how or skills may be acquired through schools and training programs, but it can take years to complete such educational programs, resulting in a lag between when

Figure 5-4

U.S. Job Creation and Destruction Rates, 1980–2012



Source: Decker et al. (2014) based on U.S. Census Bureau Business Dynamics Statistics.

firms first signal demand to the labor market and when individuals who have made decisions to join educational programs are ready to enter the workforce.

Another way high-skill workers may enter the labor market is through immigration, the total volume of which is limited by the number of visas granted, which is capped by legislation. Recent evidence shows that the contribution of skilled migration to innovation has been substantial. For example, Peri, Shih, and Sparber (2014) find that inflows of foreign science, technology, engineering, and mathematics (STEM) workers explain between 30 and 50 percent of the aggregate productivity growth that took place in the United States between 1990 and 2010. There is also abundant anecdotal evidence that the contribution of immigrants to innovation, entrepreneurship and education is substantial in the United States. Immigrants accounted for about one-quarter of U.S.-based Nobel Prize recipients between 1990 and 2000. Immigrants were also among the key founders for one-quarter of all U.S. technology and engineering companies started between 1995 and 2005 with at least 1 million dollars in sales in 2006 and for over half of such companies in Silicon Valley (Wadhwa et al. 2007). These authors also report that 24 percent of all patents originating from the United States are authored by non-citizens.

Finally, some workers may acquire skills on the job that then may be useful in future employment. Many firms, however, require their employees to sign non-compete agreements, which provide another constraint on the mobility of highly skilled workers. Removing such restrictions should lead to higher levels of labor-market dynamism such that workers are better able to find jobs matched to their skills, which should in turn lead to higher labor productivity. Recent studies suggest that the high concentrations of entrepreneurship in states like California are due to these states' non-enforcement of non-compete agreements (Gilson 1999; Marx, Singh, and Fleming 2015).

The implications of reductions in labor and firm dynamism are less clear than the trends themselves. Reduced dynamism may be a sign of better matching in job markets to begin with or increased efforts by existing firms to reduce employee turnover. Yet, reduced flows may be the result of real reductions in innovation by new firms—which is discussed below—that are driving both reduced firm and labor market dynamism. Another source of both reductions may be an expansion of non-compete clauses, occupational licensing, and other labor market institutions that preclude employees from switching jobs or starting their own businesses. Increased concentration in many industries may also play a role, regardless of its cause.

Trends in R&D Spending and Patenting

Innovation is difficult to measure directly, but spending on research and development is a critical input into innovation, and one that can be closely tracked over time. Another indirect proxy that is often used by researchers is the number of patents granted annually. This section considers both of these measures.

The Growth of Private R&D and Decline of Public R&D

Basic research discoveries often have great social value because of their broad applicability. However, because it is difficult for a private firm to appropriate the gains from basic research, there tends to be underinvestment in basic research by private firms, in the absence of public investment. As a result, economic theory predicts that aggregate R&D investment (comprised not only of basic research but also of applied research and experimental development) is bound to fall short of what is socially optimal (Nelson 1959). Recent empirical analyses that attempt to measure spillover effects suggest that the socially optimal level of R&D investment—the amount that would produce the greatest rate of economic growth—is two to four times greater than actual spending (Jones and Williams 1998; Bloom, Schankerman, and

Van Reenen 2013), and that underinvestment is particularly acute in the area of basic research (Akcigit et al. 2012).

Investing in science and technology has been one of President Obama's priorities, and these investments have included major new research initiatives such as the Precision Medicine Initiative and BRAIN Initiative (see Box 5-3 on Major Research Initiatives). Since the President took office in 2009, private R&D spending has risen as a share of the economy, reaching its highest share on record, while public R&D has fallen as a share of the economy in part due to harmful budget cuts like the sequester, as shown in Figure 5-5. In total, R&D has grown from 2.37 percent of GDP in 2004 to an estimated 2.62 percent of GDP in 2015.[7] Under the Consolidated Appropriations Act of 2016, funding for Federal R&D in FY 2016 will rise by $11.2 billion (8.1 percent) above FY 2015 levels, according to analysis by the American Association for the Advancement of Science.

Private R&D investment growth has been faster during the current recovery (post 2008) than in the prior economic expansion (2001-07), and has been especially strong in the 2013-15 period. As indicated in Figure 5-6, private R&D investment has grown at an average annual rate of 3.5 percent during the current recovery, faster than the average annual pace of 3.0 percent during the previous expansion between 2001 and 2007. Since the beginning of 2013, R&D has grown 4.9 percent at an average annual rate. Based on data available as of this writing, 2015 was the best year for private R&D growth since 2008.

Private business accounts for virtually all of the recent growth in R&D. Nonprofit institutions like universities had a negligible impact on growth. The manufacturing sector is an important driver of R&D. In 2013 and 2014, manufacturing accounted for roughly 75 percent of R&D growth and non-manufacturing accounted for the other 25 percent (see Table 5-1). Two manufacturing sectors that have notably improved relative to the pre-crisis time period (2001–2007) are semiconductors and electronic components and motor vehicles and parts. In addition, manufacturing employs 60 percent of U.S. R&D employees and accounts for more than two thirds of total

[7] There is substantial variation in the measurement of R&D depending upon the source consulted. This chapter relies upon data from the Bureau of Economic Analysis (BEA), which have the advantage of being available for 2015 as of this writing. However, BEA data do not include private firms' outlays for software development. As a result, BEA data tend to underestimate R&D's share of GDP by roughly 0.1 percentage point as compared with data from the NSF, with the size of the underestimate growing in recent years. There is, however, a significant lag in the availability of NSF R&D funding data. The Battelle forecast attempts to update the latest available data from the National Science Foundation (2013) and the Census Bureau with forecasts based on more recent micro data from other sources. The most recent forecast from the Battelle Memorial Institute projects a U.S. R&D/GDP ratio of 2.8 percent in 2014, close to its all-time highs (Grueber and Studt 2013).

Box 5-3: Major Research Initiatives

The President's FY 2017 Budget builds on seven years' worth of the Administration's science and technology priorities in a variety of policy-critical domains. Specific attention in Federal R&D funding has been paid to those societal needs that are susceptible to the classic problem of private underinvestment in public goods. In other words, many of the areas that the Administration has identified for concerted Federal R&D investment efforts are those in which individual firms or investors have limited economic incentive to commit resources, even though the overall societal benefits of these investments would be substantial. Basic research comprises a large portion of efforts that are prone to this problem.

One major area of Federal focus is the effort to combat global climate change and promote clean energy technological development, as outlined in the President's Climate Action Plan, the U.S. Global Climate Change Research Program Strategic Plan, and the Department of Energy's Quadrennial Technology Review. Detailed in these documents is the Administration's emphasis on renewable energy and electric grid modernization, the potential for improved efficiency in buildings and industry, investments in smart, multi-modal and electrified transportation systems, and technology development that would reduce greenhouse gas emissions while also improving resilience. Also relevant in this domain is an emphasis on improving our understanding of ocean and Arctic issues.

Another area of attention centers on the life sciences. Agencies have been instructed to prioritize research that could lead to positive impacts on health, energy, and food security. Chief among such priorities are the BRAIN Initiative, efforts to combat antibiotic resistance, and initiatives to improve our bio-surveillance capabilities. Mental health-related research, especially that which assists our country's veterans, is also of high priority. A final area of commitment is the Administration's Precision Medicine Initiative, which seeks to tailor medical care to the needs of the individual patient. Accordingly, investments that improve a patient's usability and portability of his or her own electronic medical records are of particular interest, subject to robust privacy controls.

A final cluster of major research initiatives involves advanced technologies, including those that bolster the Nation's security, including cybersecurity, and those that support advanced manufacturing. Such efforts focus on nanotechnology, robotics, advanced materials, bio-engineering, and high-performance computing, as well as more specific national security research priorities in the domain of data analysis, hypersonics, and counter-proliferation. Many of these initiatives involve investing in the "industries of the future," as the development and application of these technologies may yield general purpose technologies with the potential to create entirely new industries, build jobs, and increase productivity.

Ultimately, investments in these research initiatives will both improve consumer welfare and drive productivity growth in the American economy. The resultant improvements in our capacity to combat climate change, the quality of the Nation's health care, and the effectiveness of our national security efforts will form the backbone of an innovation ecosystem that benefits workers and consumers.

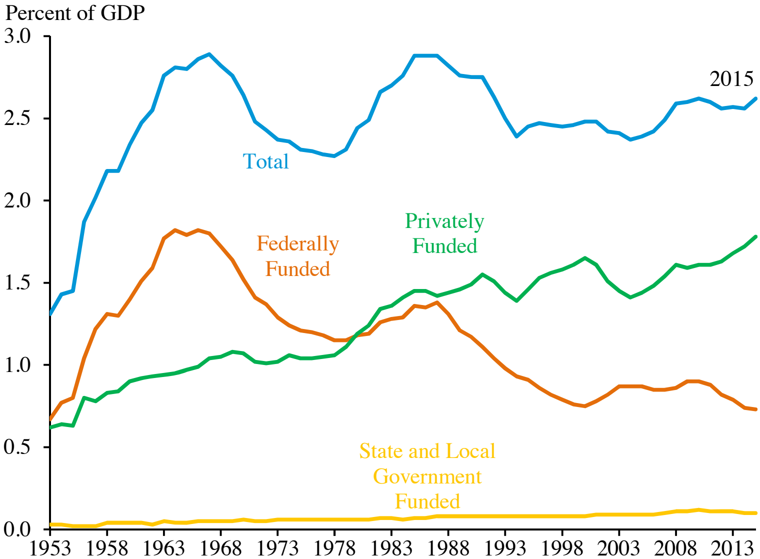
R&D volume in the United States. Manufacturing is also responsible for the vast majority of U.S. patents issued (Sperling 2013).

Federal R&D spending can be decomposed into defense and non-defense R&D spending, as displayed in Figure 5-7. Compared to most of the last decade, both defense and non-defense R&D funding have dropped slightly as a percentage of GDP in this decade. As a result of the one-time boost from the American Recovery and Reinvestment Act (ARRA), Federal R&D funding approached 1.0 percent of GDP in fiscal years 2009-10; however, subsequent Congressional appropriations have failed to maintain these gains.

The decline in federally funded R&D is potentially consequential because Federal and industry R&D investments should be thought of as complements and not substitutes for each other. The Federal R&D portfolio is somewhat balanced between research and development, while industry R&D predominantly focuses on later-stage product development. Figure 5-8 shows that the Federal Government is the majority supporter of basic research—the so-called "seed corn" of future innovations and industries that generates the largest spillovers and thus is at risk of being the most underfunded in a private market—and, as such, the Administration's efforts have prioritized increasing Federal investments in basic research while also pushing for an overall increase in Federal R&D investment.

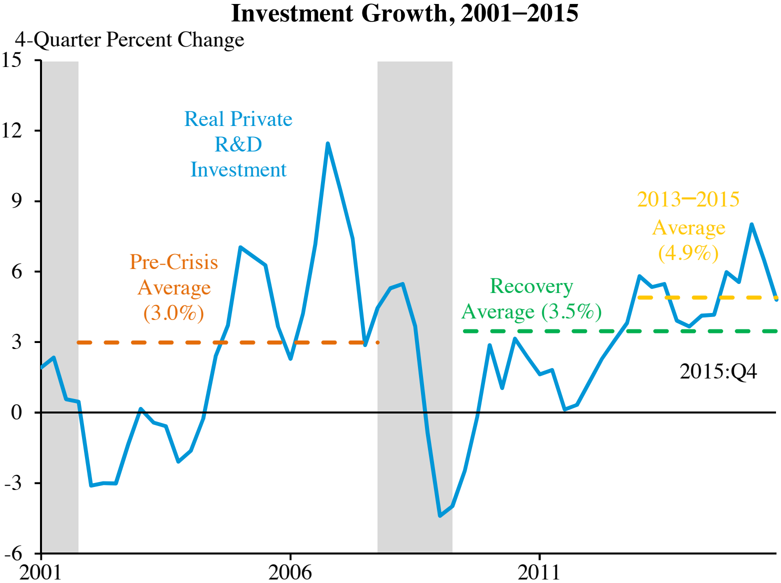
In absolute terms, the United States is the largest R&D investor in the world, with a share of about 30 percent of world R&D spending forecasted in 2014 (though second-place China is rapidly gaining share, it is only at 18 percent) (Grueber and Studt 2013). However, measured as a share of the economy, the United States ranks 10th in R&D among countries in the Organisation for Economic Co-operation and Development (see Figure 5-9). Unlike the United States, most of the other economies in the top 10

Figure 5-5
Federal and Nonfederal Research and Development as a Share of GDP, 1953–2015



Source: Bureau of Economic Analysis.

Figure 5-6
Real Private Research & Development (R&D) Investment Growth, 2001–2015



Note: Shading denotes recession. Pre-crisis average defined as Q4:2001 through Q4:2007.
Source: Bureau of Economic Analysis.

Table 5-1

Contribution to Average Annual Growth of R&D Investment

Sector	Percentage Points		
	2001-2007 Average	2013-2014 Average	Change
Total Business	2.3	4.8	2.5
Manufacturing	2.5	3.6	1.1
Pharmaceutical and Medicine	1.8	1.6	-0.2
Chemical ex Pharmaceutical	0.0	-0.1	-0.1
Semiconductors and Electronic Components	0.4	0.7	0.3
Other Computer and Electronic Products	-0.2	0.2	0.3
Motor Vehicles and Parts	-0.1	0.3	0.4
Aerospace Products and Parts	0.2	0.2	0.0
Other Manufacturing	0.4	0.7	0.3
Non-Manufacturing	-0.2	1.2	1.4
Scientific R&D Services	0.1	-0.3	-0.4
All Other Non-Manufacturing	-0.3	1.5	1.8
Total Non-Business	0.1	0.0	-0.1
Universities and Colleges	0.1	0.0	-0.1
Other Nonprofits	0.1	0.0	0.0
Headline R&D Growth	2.4	4.8	2.4

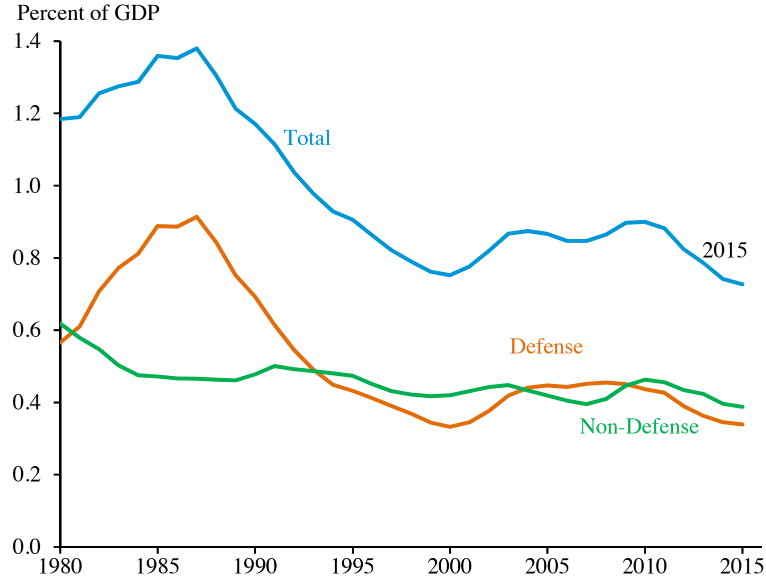
Source: Bureau of Economic Analysis; CEA Calculations

continue to expand their R&D investments from all sources—not just private ones—faster than their economic growth.[8]

Federal R&D is important not only for private firms' success, job creation, or aggregate measures of productivity. Federally funded research leads to innovations that improve consumer welfare as well, with a host of products and services being made possible by such investments—be they in the area of basic or applied research investigations. From Google Earth and global positioning systems to microwave ovens, and from vaccinations to photovoltaic cells, discoveries and products enabled by U.S. Federal investments in innovation have touched lives across the globe in ways that are likely to be understated in official growth and productivity statistics (see Chapter 2). Investments in R&D are therefore important to the health of the American economy as well as to general welfare. The innovations that these

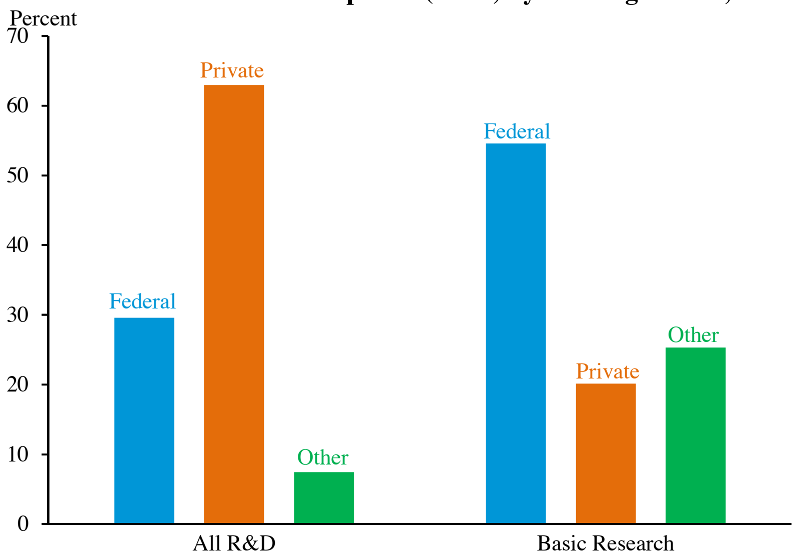
[8] For comparison, Europe as a whole was forecast by Battelle to have an R&D/GDP ratio of 1.8 percent in 2014; China's R&D/GDP ratio was forecast at 2.0 percent but climbing rapidly. South Korea, Israel, Japan, Sweden, Finland, Denmark, Switzerland, Austria, and Germany are the 9 OECD economies ahead of the United States.

Figure 5-7
Federal Research and Development (R&D) Investment, 1980–2015



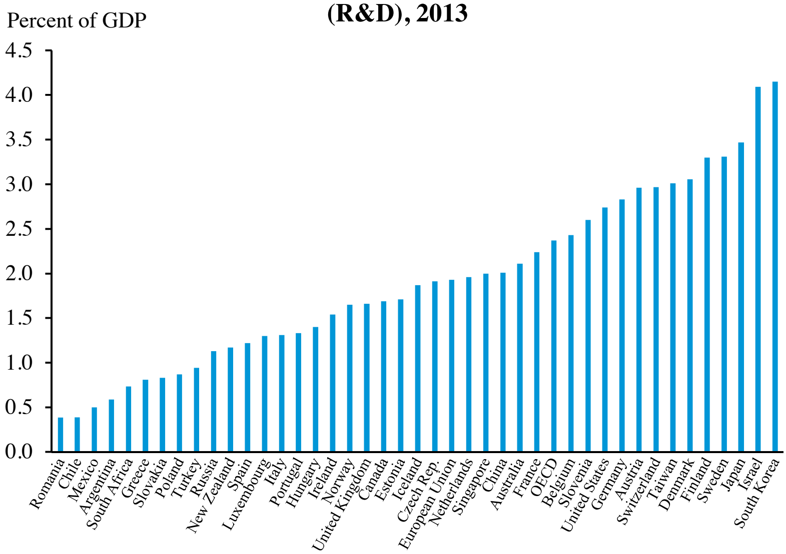
Source: Bureau of Economic Analysis.

Figure 5-8
Share of Research and Development (R&D) by Funding Source, 2011



Source: National Science Foundation, Science and Engineering Indicators 2014, Table 4-3.

Figure 5-9
Gross Domestic Expenditure on Research and Development (R&D), 2013



Note: Data for South Africa and Switzerland are not available for 2013 and so are instead displayed for the most recent available year.
Source: OECD Main Science and Technology Indicators (2015).

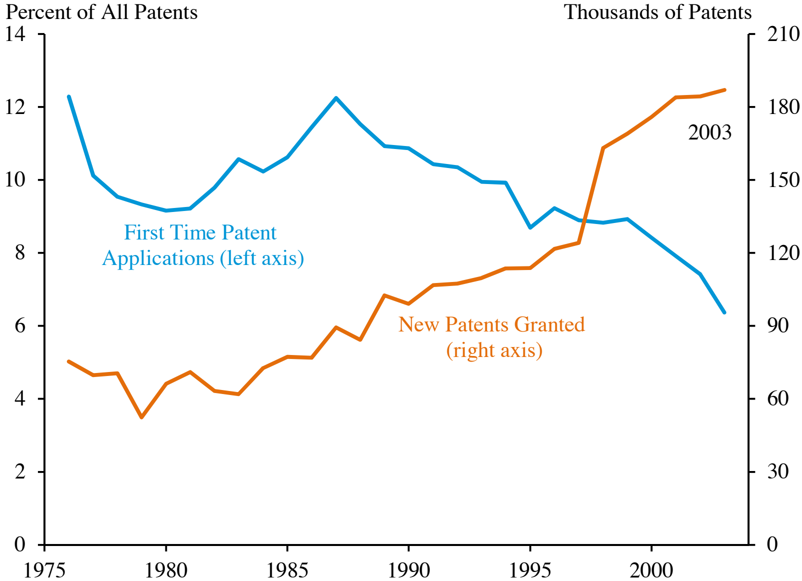
investments in R&D generate help lower costs and boost productivity, and the firms that these investments spawn compete with established firms, further driving innovation and productivity growth (Griliches 1986; Griliches 1992; Jones 2002; Jones and Williams 1998).

Recent Trends in Patenting

Although innovation is notoriously difficult to quantify, patents provide one measure of innovative activity. The link between patent grants and aggregate productivity growth is tenuous, because patenting can be driven by numerous factors, including the budget of the U.S. Patent and Trademark Office (Griliches 1989). Thus, while the number of new patents granted has increased over the past several decades (Figure 5-10, right axis), the extent to which this trend is indicative of current or future productivity growth is unclear.

Recent academic findings at the firm level, however, suggest that higher levels of patenting are associated with higher total factor productivity. For example, Balasubramanian and Sivadasan (2011) find evidence that a firm's productivity increases following its first patent. The U.S. Census Bureau and U.S. Patent and Trademark Office have started to link patent application data to administrative data on firms and workers. Initial research using this data indicates that most patenting firms are small, and that firms

Figure 5-10
Percent of Patent Applications by First Time U.S. Patenters, 1976–2003



Source: NBER Patent Database; U.S. Patent and Trademark Office; CEA calculations.

that patent are responsible for creating more jobs and shedding fewer jobs than non-patenting firms (Graham et al. 2015). Given evidence of slowing business dynamism and lower rates of entry by new firms discussed in the previous section, these new findings would then suggest that the share of patents by new firms is slowing over time. Figure 5-10 (left axis) graphs the percent of patents by first-time patent applicants (many of which are young or startup firms) from 1976 to 2003. While patenting has increased over time, the percent of patents by first-time applicants has been declining since the late 1980s, implying at the very least that the majority of the recent increase in the overall number of patents in the U.S. economy is likely not driven by first-timers.

The reasons behind the falling share of first-time patent applicants are not well understood. It may be that there are economies to scale in patenting, and so larger firms are patenting at a higher rate than startups. It may be that younger firms are starting to rely on trade secrets rather than patents; indeed, Png (2015) provides evidence that trade secrets may substitute for patents in some industries. It may be that costs associated with litigation disproportionately affect young firms (see Box 5-4 on Patent Litigation).

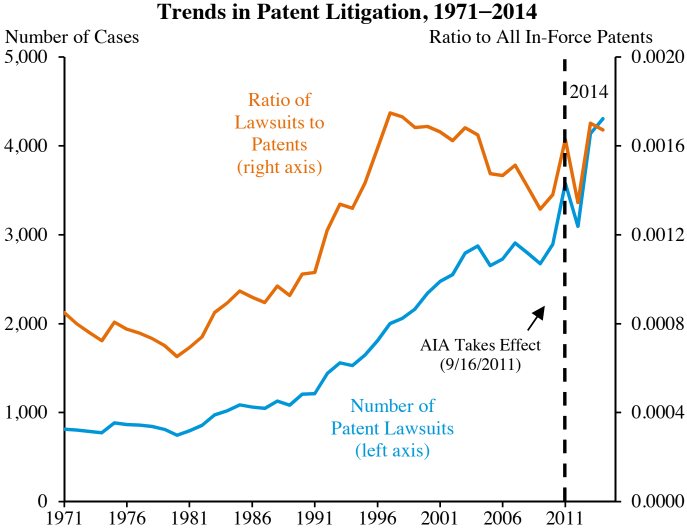
Strong institutions that protect property rights are an important ingredient for fostering economic activity and entrepreneurial success (Acemoglu, Johnson, and Robinson 2005; North and Weingast 1989). But

Box 5-4: Patent Legislation

While the number of annual patent grants have increased dramatically over the past several decades (Figure 5-10 above), so too has the amount of patent litigation (Figure 5-ii below, left axis). The rate of patent litigation, defined as the ratio of the number of patent litigation cases to the number of in-force patents, increased from the 1970s to mid-1990s, then fell from the mid-1990s to 2010, before increasing through 2014. (Figure 5-ii below, right axis). Some of the increase in patent litigation occurred after the America Invents Act (AIA) took effect in 2011. Part of the increase may have been due to the AIA's change in the "joinder rule" that previously allowed multiple cases involving a single infringed patent to be joined. Part of the increase may have also been due to a temporary increase in false marking cases (PWC 2013).

Patent litigation cases are brought by both non-practicing entities (NPEs) and practicing entities (PEs). NPEs are organizations that own patents on products or processes but do not make, use, or sell them. These include patent assertion entities (PAEs) that specialize in asserting patents, as well as individual inventors and universities who solely license patents to others (Lemley and Melamed 2013). PEs are organizations that own patents on products or processes that they make, use, or sell. According to research by RPX (2014; 2015), the percent of patent litigation cases brought by NPEs has grown over time, from below 30

Figure 5-ii
Trends in Patent Litigation, 1971–2014



Note: AIA stands for the Leahy-Smith America Invents Act.
Source: USPTO; FJC; Lex Machina; CEA calculations.

percent of all cases in 2009 to over 60 percent in 2014. The majority of NPE cases are filed by PAEs, estimated to be 89 percent of all NPE cases by RPX (2015).

Patent litigation appears to negatively affect entrepreneurship and innovation. Chien (2015) reports that patent litigation disproportionately affects smaller companies. Kiebzak, Rafert, and Tucker (2016) conclude that venture capital investment, an indicator of levels of entrepreneurial activity, initially increases with the number of litigated patents, but that past a certain threshold, further increases in litigated patents are associated with decreased venture capital investment. The authors also find some evidence that a similar relationship exists between patent litigation and small firm entry. Scott Morton and Shapiro (2014) develop a theoretical model to assess how patent litigation affects innovation. When they fit the model with existing data, the results suggest that patent litigation hurts innovation. Feldman and Lemley (2015) find that very few patent license demands lead to new innovation but rather involve payment by the licensee to continue with its business. Galasso and Schankerman (2015) exploit the randomized assignment of judges to find that patent invalidation results in a 50 percent decrease in future patenting over a five-year window.

property rights protection regimes must balance addressing valid concerns with guarding against baseless or excessive complaints. This tradeoff is particularly important as the frequency of patent litigation has risen. With this goal in mind, the President has supported efforts to reform the U.S. patent system, including signing the America Invents Act (AIA) in September 2011. Among other changes called for in the AIA, there are now limits on the ability of patent holders to name (or "join") multiple defendants in a single patent infringement lawsuit. More work is needed to reform patent litigation and better align rewards provided to patent holders with their social contribution. By instituting reforms that better protect and incentivize innovators, motivate more entrepreneurial startups to enter and compete against established firms, and encourage workers to seek employment opportunities that are best matched to their skillset, the Administration aims to foster productivity growth.

New Opportunities and Challenges

There are many opportunities for new technologies and business models to spur innovation and productivity growth. The range of technologies—from clean energy technology to biotechnology to 3-D printing technology—is broad. This section focuses on two new opportunities that have the potential for broad spillovers into different parts of the economy. One area is the rapidly growing field of robotics. The other area involves Internet communications technology. While these areas offer much promise, there are also a variety of challenges that result from their deployment and increasing role in American life. For example, it is important that the resultant gains from productivity growth from these technologies are shared widely.

More specifically, in the area of robotics, this section explores concerns that increased automation in the workplace threatens to displace elements of the conventional labor force. It is important to keep in mind that, while growing quickly, robotics are not poised to affect every area of the economy or replace human labor. Nonetheless, robotics still have the potential to be highly consequential for firms and, more broadly, for productivity.

This section also discusses two particular facets of Internet communications technology, namely the on-demand economy and the digital divide. The rise of the so-called on-demand economy—enabled by mobile Internet applications—also has the potential for productivity and welfare gains but could possibly lead to worker displacement, a prospect that is examined here as well. This section also emphasizes the need to narrow what is commonly called the digital divide—the gap between those who can access the Internet and those who cannot—so that all may share in its benefits, the existence of which is well-supported by empirical findings in the economics literature.

Robotics

One area of innovation that can help the United States to boost TFP growth in the future is robotics. The first U.S. robots were introduced into production by General Motors in 1961, and their prevalence has grown steadily over time, particularly in manufacturing and the auto industry (Gordon 2012). Recently, the deployment of robots has accelerated, leading them to contribute more to productivity, as described below. However, these changes potentially also create challenges in labor markets as concerns have arisen about the extent to which robots will displace workers from their jobs. An economy must carefully assess these developments to encourage innovation but also to provide adequate training and protections for workers.

The use of industrial robots can be thought of as a specific form of automation. As a characteristic of innovation for centuries, automation enhances production processes from flour to textiles to virtually every product in the market. Automation, including through the use of information technology, is widely believed to foster increased productivity growth

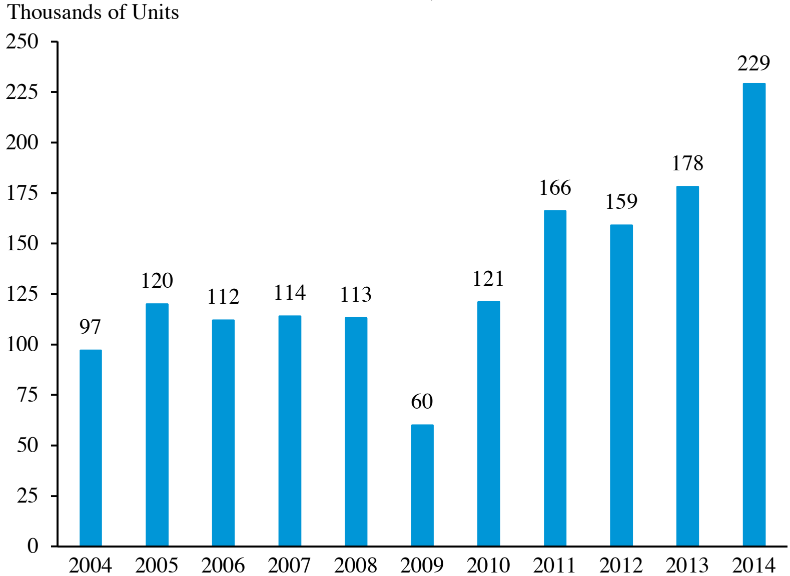
(Bloom, Sadun, and Van Reenen 2012). In many cases, mostly for higher-skilled work, automation has resulted in substantial increases in living standards and leisure time. The International Organization for Standardization (ISO) defines a robot to be an "actuated mechanism programmable in two or more axes with a degree of autonomy, moving within its environment, to perform intended tasks."[9] This degree of autonomy makes robotic automation somewhat different from historical examples of automation, such as the replacement of weavers with looms. Some of these machines can operate for extended periods of time without human control, presaging the rise of a potentially paradigm-shifting innovation in the productivity process.

Robots, like other types of automation, can be either complements to, or substitutes for, conventional labor. For example, at many of the country's biggest container shipping ports—the primary gateways to and from the United States for waterborne international shipments—automation has replaced longshoremen in a variety of activities, from computerized cargo management platforms that allow for visualization of the loading of a container ship in real time to software that allows for end-to-end management of individual containers throughout the unloading process (Feuer 2012). By contrast, there are a number of "smart warehouse" applications that involve varying amounts of automation to complement the work done by warehouse fulfillment workers. Examples include LED lights on shelves that light up when a worker reaches the appropriate location and mobile robots that bring inventory from the floor to a central place for packaging (Field 2015; Garfield 2016). The latter example realigns employees away from product-retrieval tasks and focuses them instead on the inventory-sorting phase of the process, for which humans have a comparative advantage over machinery.

Robotics have also played an important role in growth over the last two decades. A recent study estimates that robotics added an average of 0.37 percentage point to a country's annual GDP growth between 1993 and 2007, accounting for about one-tenth of GDP growth during this time period (Graetz and Michaels 2015). This same study also estimates that robotics added 0.36 percentage point to labor productivity growth, accounting for about 16 percent of labor productivity growth during this time period. This effect is of similar magnitude to the impact that the advent of steam engines had on labor productivity growth (Crafts 2004).

[9] Note that the requirement for a "degree of autonomy" can be fulfilled with anything from indirect interaction between human control inputs and the physical robot all the way up to full autonomy (ISO 8373, 2012, available at https://www.iso.org/obp/ui/#iso:std:iso:8373:ed-2:v1:en).

Figure 5-11
Estimated Worldwide Annual Supply of Industrial Robots, 2004–2014

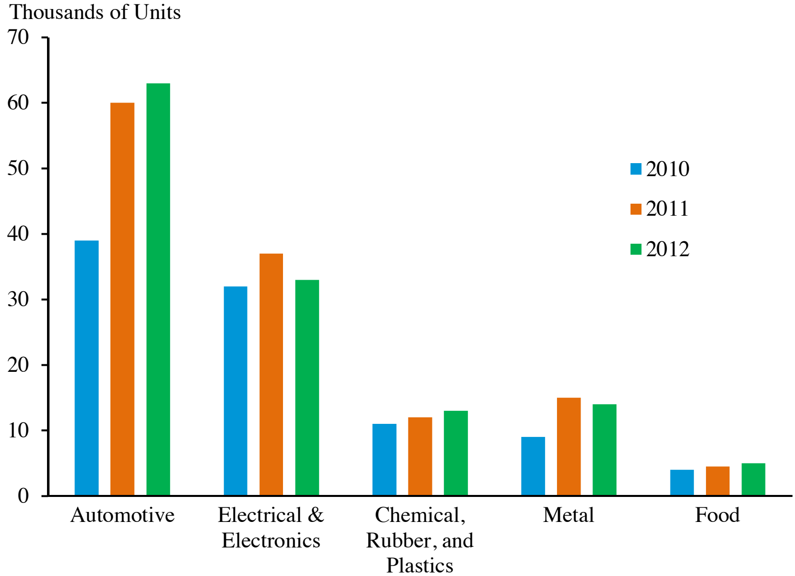


Source: International Federation for Robotics, World Robotics 2015.

Growth in robotics shipments has increased since 2007, suggesting that robotics may contribute even more to GDP and labor productivity growth in the future, though it is too early to tell. As indicated in Figure 5-11, from 2010 to 2014, worldwide shipments of industrial robotics have nearly doubled, according to the International Federation of Robotics (IFR). Research by the Boston Consulting Group also estimates that the dollar value of these industrial robotics shipments likely doubled during this time period (Sander and Wolfgang 2014). These estimates may even understate the pace of growth, since the IFR defines an industrial robot by ISO standard 8373: "An automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes, which may be either fixed in place or mobile for use in industrial automation applications." In particular, the requirement that the device be reprogrammable to be considered an industrial robot may result in an undercount compared to other robotics definitions.

Industrial-services robots are primarily applied to manufacturing activities. The automotive sector accounts for approximately 40 percent of total robot shipments worldwide, and has seen rapid growth in shipments since 2010. Consumer electronics is the second-largest sector, comprising 20 percent of total shipments; other large sectors include chemical rubber and plastics, metal, and food processing, as indicated in Figure 5-12.

Figure 5-12
Estimated Annual Shipments of Industrial Robots by Main Industries, 2010–2012



Source: International Federation for Robotics, World Robotics 2014.

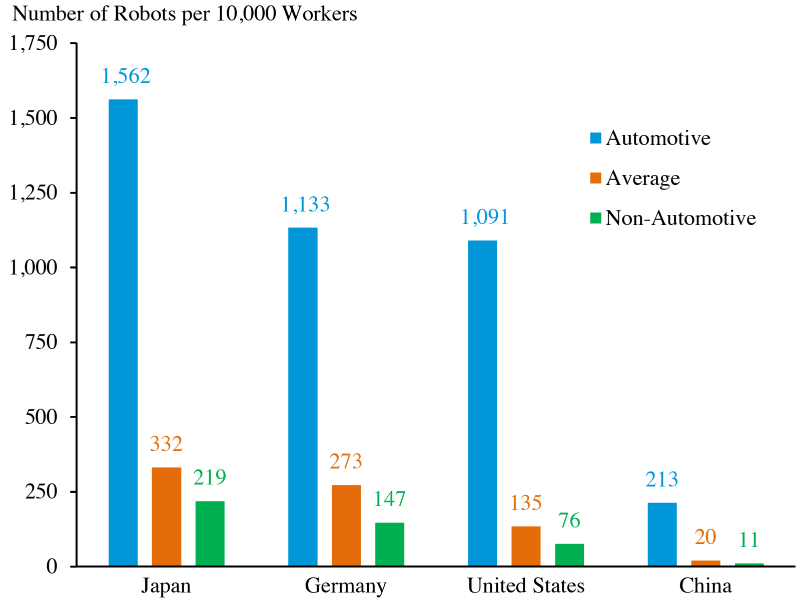
Robotics are used in different ways across different industries. Figure 5-12 depicts changes over time within several industries and, in particular, highlights the rapid growth within the automotive industry. Another way to compare the intensity of robot use across industries is to normalize the number of robot units in the industry by the number of workers in the industry to create a "robot density." Figure 5-13 compares the robot density across industries and across countries. Again, the automotive industry appears to be the heaviest user of robots, both in terms of absolute number of robot units (shown in Figure 5-12) and in terms of density of robots per worker (illustrated by Figure 5-13). This trend may be because the skillset of robots lends itself well to the standardization and fixed nature of the automotive assembly process. The comparison also reveals that the United States lags Japan and Germany in the number of robots per worker, especially outside the automotive sector.

To examine the pace of innovation in robotics, CEA collected data directly from the U.S. Patent and Trademark Office on the total number of patents granted each year, as well as the number of robotics patents, from 2000 to 2014.[10] Figure 5-14 shows that the number of patents in this class

[10] Patents were counted as being "robotics patents" if they received the patent subclass number 901 (robots). For more information, see the USPTO's definition: http://www.uspto.gov/web/patents/classification/uspc901/defs901.htm.

Figure 5-13

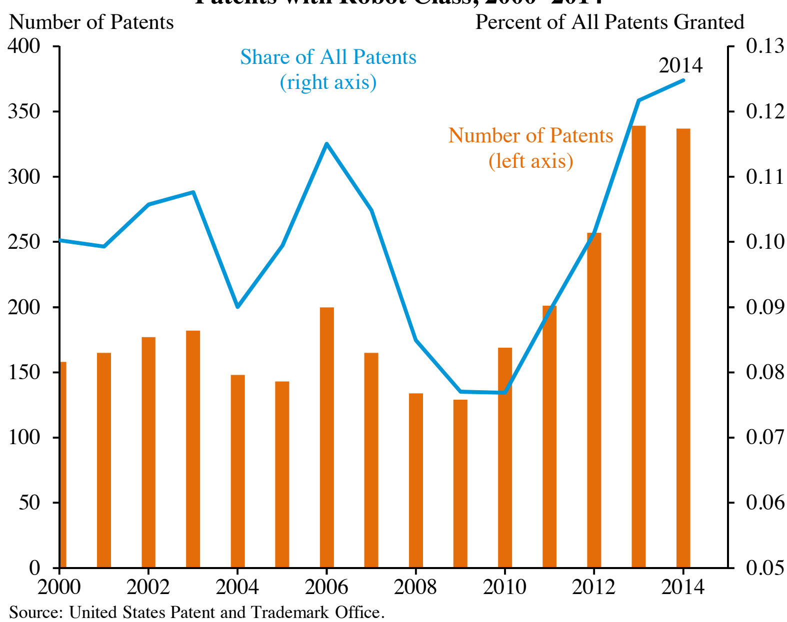
Robot Density: Automotive vs. Non-Automotive, 2012



Source: Axium Solutions; International Federation for Robotics.

Figure 5-14

Patents with Robot Class, 2000–2014



Source: United States Patent and Trademark Office.

was relatively flat through the 2000s, before starting to increase in 2012. There were close to 350 robotics patents granted in both 2013 and 2014, as compared to an average of about 150 in the 2000s. As also indicated in Figure 5-14, the share of patents that are for robotics decreased from 2006 to 2010 before starting to increase from 2011 to 2014.

CEA also conducted an analysis of patent ownership and found little evidence of concentrated ownership across industries. However, robotics are used differently across industries, and so it is unclear whether there is a concentration of patent ownership within different industries. Going forward, it will be important to be vigilant about intellectual property related to robotics. Low concentration in upstream markets implies healthy competition, which should lead to more innovation and lower prices. As a result, downstream firms should be able to acquire robot inputs at competitive prices, which should help to drive productivity growth even further.

Effect of Robotics on Workers

While industrial robots have the potential to drive productivity growth in the United States, it is less clear how this growth will affect workers. One view is that robots will take substantial numbers of jobs away from humans, leaving them technologically unemployed—either in blissful leisure or, in many popular accounts, suffering from the lack of a job. Most economists consider either scenario unlikely because several centuries of innovation have shown that, even as machines have been able to increasingly do tasks humans used to do, this leads humans to have higher incomes, consume more, and creates jobs for almost everyone who wants them. In other words, as workers have historically been displaced by technological innovations, they have moved into new jobs, often requiring more complex tasks or greater levels of independent judgment.

A critical question, however, is the pace at which this happens and the labor market institutions facilitate the shifting of people to new jobs. As an extreme example, if a new innovation rendered one-half of the jobs in the economy obsolete next year, then the economy might be at full employment in the "long run." But this long run could be decades away as workers are slowly retrained and as the current cohort of workers ages into retirement and is replaced by younger workers trained to find jobs amidst the new technological opportunities. If, however, these jobs were rendered obsolete over many decades then it is much less likely that it would result in large-scale, "transitional" unemployment. Nevertheless, labor market institutions are critical here too, and the fact that the percentage of men ages 25-54 employed in the United States slowly but steadily declined since the 1950s, as manufacturing has shifted to services, suggests that challenges may arise.

Over time, economists expect wages to adjust to clear the labor market and workers to respond to incentives to develop human capital. Inequality could increase; indeed, most economists believe technological change is partially responsible for rising inequality in recent decades. Whether or not robots will increase or decrease inequality depends in part on the extent to which robots are complements to, or substitutes for, labor. If substitution dominates, then the question becomes whether or not labor has enough bargaining power such that it can share in productivity gains. At present, this question cannot be answered fully, largely because of limited research on the economic impact of robots. One of the few studies in this area finds that higher levels of robot density within an industry lead to higher wages in that industry (Graetz and Michaels 2015), suggesting that robots are complements to labor. The higher wages, however, might be due in part to robots' replacing lower-skill workers in that industry, thus biasing wage estimates upwards.

The older literature on automation may give some clues about how robots will affect jobs in the future. This broader literature finds that, while there is some substitution of automation for human labor, complementary jobs are often created and new work roles emerge to develop and maintain the new technology (Autor 2015). One issue is whether these new jobs are created fast enough to replace the lost jobs. Keynes (1930) appears to have been concerned about the prospect for what he termed "technological unemployment," borne out of the notion that societies are able to improve labor efficiency more quickly than they are able to find new uses for labor.

There has been some debate about which types of workers are most affected by automation. That is, jobs are not necessarily destroyed by automation but instead are reallocated. Autor and Dorn (2013) argue that so-called middle-skill jobs are what get displaced by automation and robots. These jobs, which have historically included bookkeepers, clerks, and certain assembly-line workers, are relatively easy to routinize. This results in middle-skill workers who cannot easily acquire training for a higher-skilled job settling for a position that requires a lower-skill level, which may then translate into lower wages. In contrast, high-skill jobs that use problem-solving capabilities, intuition and creativity, and low-skill jobs that require situational adaptability and in-person interactions, are less easy to routinize. Autor, Levy, and Murnane (2003) point out that robots and computerization have historically not been able to replicate or automate these tasks, which has led to labor market polarization. While not specifically tied to automation, Goos, Manning, and Salomons (2014) find broad evidence of this labor market polarization across European countries.

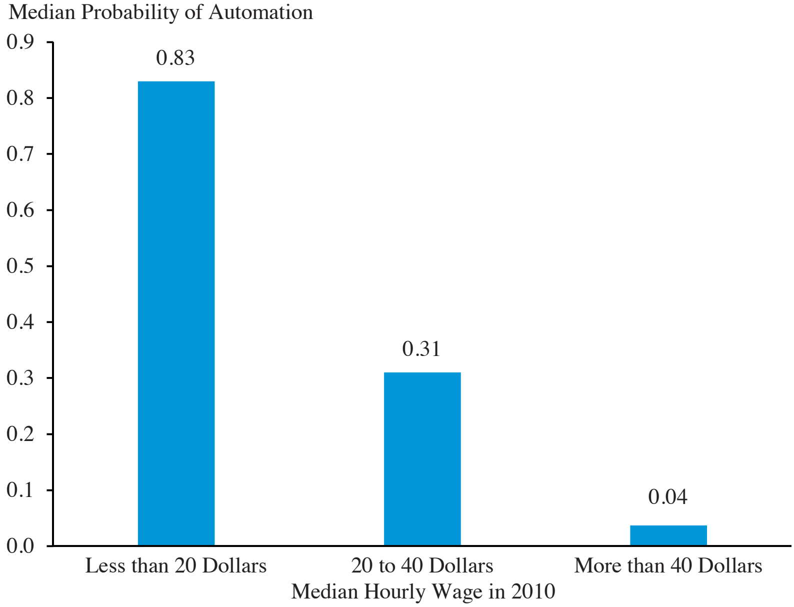
In contrast, recent papers by Autor (2015) and Schmitt, Shierholz, and Mishel (2013) suggests that the labor market polarization seen in the 1980s and 1990s may be declining. Data from the 2000s suggests that lower- and middle-skill workers have experienced less employment and wage growth than higher-skilled workers. Frey and Osborne (2013) argue that big data and machine learning will make it possible to automate many tasks that were difficult to automate in the past. In a study specifically on robots and jobs, Graetz and Michaels (2015) find some evidence that higher levels of robot density within an industry lead to fewer hours worked by low-skilled workers in that industry.

While robotics is likely to affect industrial sectors of the economy differently, it also is likely to affect occupations within these sectors differently. Two recent studies have used data on occupational characteristics to study how automation might differentially affect wages across occupations (Frey and Osborne 2013; McKinsey Global Institute 2015). Both studies rely on the detailed occupational descriptions from O*NET, an occupational data source funded by the U.S. Department of Labor, to derive probabilities that an occupation will be automated into obsolescence. While the two studies have slightly different categorizations, they both find a negative relationship between wages and the threat of automation.

To better understand the relationship between automation and wages at the occupational level, CEA matched an occupation's median hourly wage to the occupational automation scores from Frey and Osborne (2013). The median probability of automation was then calculated for three ranges of hourly wage: less than 20 dollars; 20 to 40 dollars; and more than 40 dollars. The results, presented in Figure 5-15, suggest that occupations that are easier to automate have lower wages. Low probability of outright automation, however, would seem to make an occupation a better candidate for being complemented and improved by automation in the workplace (such as the role played by e-mail, statistical analysis, and computerized computation for a variety of office-based jobs) and so are not as prone to seeing an effect on wages from increased automation.

These data demonstrate the need for a robust training and education agenda, to ensure that displaced workers are able to quickly and smoothly move into new jobs. The bipartisan Workforce Innovation and Opportunity Act, which President Obama signed into law in July 2014, consolidates existing funding initiatives, helps retrain workers in skills that employers are looking for, and matches those workers to employers. In March 2015, the Administration launched the TechHire initiative, part of which aims to equip 17-29 year olds with skills necessary for jobs in information

Figure 5-15
Probability of Automation by an Occupation's Median Hourly Wage



Source: Bureau of Labor Statistics; Frey and Osborne (2013); CEA calculations.

technology fields, including software development, network administration, and cybersecurity.

Internet and New Business Models

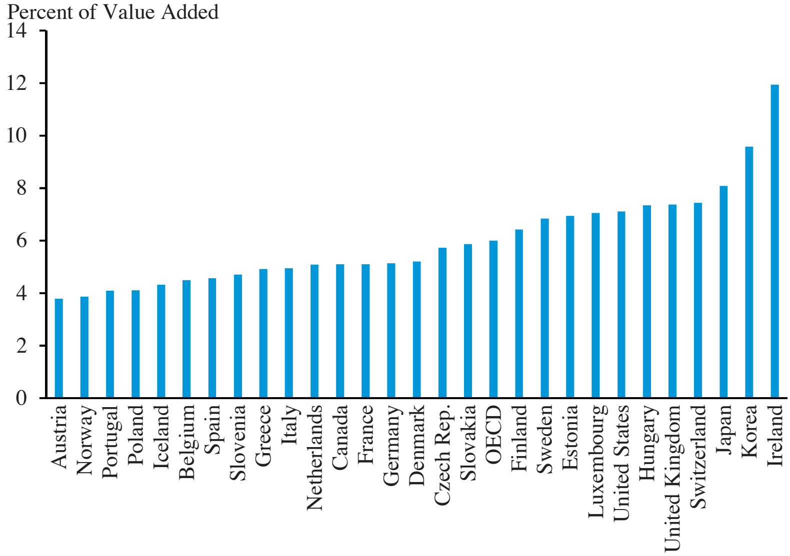
Digital communications technology is an area that has had a large impact on TFP growth. Such technologies are what some economists call General Purpose or "platform" technologies, meaning that improvements in communication technologies stimulate innovation across a wide variety of other sectors. This growth is expected to continue in the future as the Internet is used to connect employers to employees, to connect customers to suppliers, and to develop new businesses and business models that deliver products and services faster than in the past. Moreover, these new businesses compete with established firms, in many cases pushing existing businesses to innovate further, thereby providing customers with better products and services at lower prices. Competition can therefore lead to higher living standards, as customers can purchase a wider variety of products at lower prices.

The United States is among the world leaders in the development and deployment of cutting-edge broadband technology. Today, most Americans live in areas served by fixed-line Internet services, and the United States enjoys widespread availability of advanced wireless broadband Internet services, such as 4G LTE. At the same time, broadband access has become a nearly indispensable component of modern life. Numerous studies show that access to broadband contributes to local, regional, and national economic growth. A study of Organisation for Economic Co-operation and Development (OECD) countries finds that a 10 percentage-point increase in broadband penetration is associated with per capita income growth rates that are between 0.9 and 1.5 percentage points higher (Czernich, Falck, Kretschmer, and Woessmann 2011). Another cross-country analysis finds that a 1 percent increase in the size of a country's Internet-using population is associated with 8 to 15 dollars more in GDP per capita (Najarzadeh, Rahimzadeh, and Reed 2014). Kolko (2012), using panel data and instrumental variables approaches, finds that local broadband expansion leads to local employment growth.

These findings parallel a broad literature linking Internet and communications technology (ICT) to productivity. For example, Bartel, Ichniowski, and Shaw (2007) find that computerized numerically controlled machining centers can both lead to wider product variety and improve overall production efficiency. More generally, growth in the use of computers, as well as the changes in management and other organizational dynamics that ensued, partially explains the recovery in TFP growth during the 1990s from its historic lows in the 1970s and 1980s (Black and Lynch 2004). While the United States benefited from the integration of these technologies and management techniques, other countries that also invested in ICT did not see as large a pickup in productivity. Although the United States leads most other Western economies in both the share of ICT in value added (Figure 5-16) and TFP growth rates, some countries that lead the world in the former exhibit low levels of the latter.

Access to the Internet not only enables firms to increase productivity, but it also provides an opportunity for entrepreneurs to experiment with innovative product ideas and new business models, and scale these ideas and models up quickly and cheaply. For example, on-demand economy platforms would not be possible but for the widespread adoption of Internet and wireless devices (see Box 5-5 on On-Demand Economy). Not only do these new business models help lower costs for consumers, leading to greater consumer surplus, but also they may increase business productivity. For example, a survey of San Francisco transportation-network company (TNC) riders by University of California-Berkeley researchers found that TNC wait times were dramatically shorter and more consistent than taxis (Rayle et al. 2014). Shorter wait times mean that a worker is able to travel between meetings or work and home quicker than before, raising the amount of time a worker is able to spend being productive. As another example, entry

Figure 5-16
Share of Information and Communications Technology (ICT) in Value Added, 2011



Source: OECD Factbook.

of online craft markets means that many craft artisans are able to increase exposure in multiple markets, leading to increased scale and ultimately productivity growth, much in the same way that higher exports from international trade leads to productivity growth. These business models also introduce new competitive dynamics into established industries.

The Digital Divide Challenge

Broadband access has become a nearly indispensable component of modern life, used for everything from engaging in personal communication, to searching for a job, and streaming online educational content to engaging in civic affairs (National Telecommunications and Information Administration and Economics and Statistics Administration 2013). Thus, access to the Internet has become an essential resource for many nascent entrepreneurs to reach potential customers. Customers who access the Internet can benefit from the array of new products and services offered by certain types of entrepreneurial new firms. However, a digital divide (for example, the fact that certain groups of individuals and businesses lack access to the Internet) means that some would-be entrepreneurs cannot compete, and some would-be customers cannot access these new products and services.

Box 5-5: The On-Demand Economy

"On-demand economy platforms" are online and mobile platforms that match consumers to providers for the purpose of purchasing goods or services on a "one-off" basis. This intentionally broad definition includes the following types of platforms:

- *Rental platforms* most commonly involve homeowners renting out their homes to business and vacation travelers. Other assets can also be rented through similar arrangements, such as car and bicycle rentals.
- *Craft platforms* allow individuals and small businesses who produce or collect craft-oriented goods to sell these goods to consumers.
- *Financing platforms* allow individuals and small firms to obtain financing from lenders, in exchange for fixed payments, equity, or rewards.
- *"Gig" platforms* allow individual providers to provide their labor services, which might be tied to a specialized physical asset, such as a car in the case of transportation-network companies (TNCs), or a specialized human asset, such as the ability to code, to individual consumers and small firms.

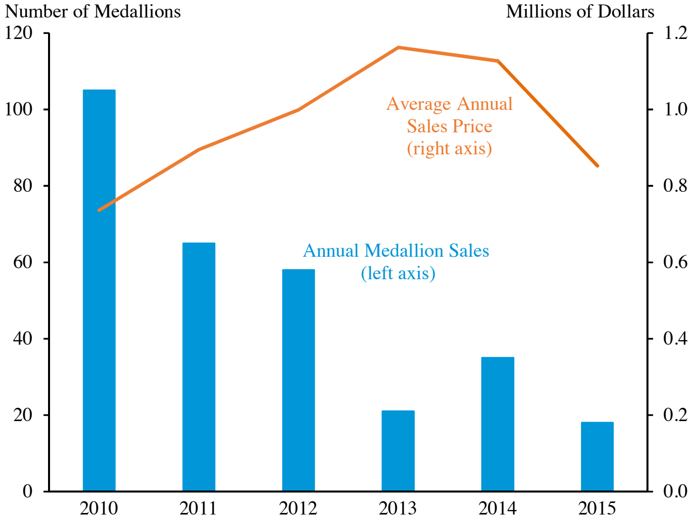
Because they are so nascent, relatively little economic research has been done on these models. Moreover, many of these activities cannot be isolated in official economic statistics and, in some cases, may in fact be omitted from these statistics. At present, this portion of the economy still appears relatively small—estimates suggest that it represents less than 1 percent of the working-age population and only accounts for a miniscule portion of the economy as a whole; PricewaterhouseCoopers estimated global revenues for the on-demand economy to be $15 billion in 2014 (PWC 2015). However, these business models are growing rapidly, and McKinsey Global Institute predicts these business models will increase global GDP by $2.7 trillion by 2025 (Manyika et al. 2015).

These platforms are already forcing incumbents to respond in several industries—notably the taxi industry in which TNCs have rapidly gained popularity and the lodging industry. For example, one independent study found that entry of an online housing rental platform led to lower hotel prices in Texas (Zervas, Proserpio, and Byers 2015). As noted above on the dual role of startups, there do not need to be many startups in an industry before the incumbents in that industry start to undertake changes to guard against business losses. These actions could take the form of innovative activity, which would boost both firm-level and overall economic productivity, or dropping prices, which would improve consumer welfare.

Medallion prices in New York City and Chicago have fallen substantially since the introduction of TNCs, which is indicative of increased competition in the taxi market.[1] Medallions in New York City and Chicago are treated as private assets, and the total number of medallions is limited by city government organizations—a practice that effectively caps the quantity of rides available. Demand for rides in these cities has previously exceeded the cap, so the medallion system works to sustain city-determined, artificially-high fares, resulting in rents for taxi medallion owners via this rationing process. Figure 5-iii below for New York City shows that the average price for a single taxi medallion, which had been increasing since 2010, started to fall in 2013. Similarly, the number of taxi medallion transfers has dropped during this time. Figure 5-iv below for Chicago reveals similar trends in that prices started to fall in 2013. By the end of 2015, the average transaction price for a medallion in Chicago had fallen to $230,000, less than two-thirds of its value of two years earlier. The number of medallions sold has also dropped during this time.

Consumers appear to benefit from the on-demand economy because of lower prices and a greater array of options, including pro-

Figure 5-iii
New York City Taxi Medallion Transactions, 2010–2015



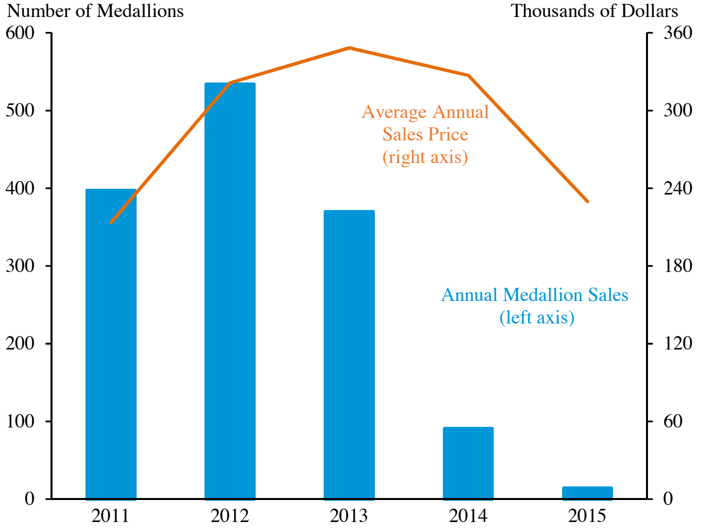
Source: New York City Taxi and Limousine Commission, Medallion Transfers.

[1] Data on New York City taxi medallion transfers can be found at: http://www.nyc.gov/html/tlc/html/about/medallion_transfers.shtml. Data on Chicago taxi medallion transfers can be found at: https://www.cityofchicago.org/city/en/depts/bacp/supp_info/medallion_owner_information.html. CEA aggregated the data by month and year to examine the number of medallion transfers and average value of transfer.

vision of services that may not have previously existed or now reach new geographic areas. While the evidence suggests that consumers benefit from competition between on-demand economy platforms and incumbent firms, the effect on wages and inequality is less certain. The optimistic view is that this sector will be a source of productivity growth that will increase consumer purchasing power across-the-board as well as set an example of technological innovations complementing low- and mid-skilled workers, thus putting downward pressure on income inequality. The pessimistic view is that, to the degree the on-demand economy prospers because of regulatory arbitrage, it will not increase productivity and could diminish social welfare. In this view, the firm that is able to circumvent regulations that correct for a negative externality in the marketplace (such as labor protection laws or safety regulations) will lead market transaction volume to a quantity that is higher and a quality that is lower than optimal. Moreover, dispersed employees will have a hard time organizing for higher wages, so low- and mid-skilled workers will be hurt, and certain features of the market could lead to high firm concentration. Regardless of which view prevails, or which aspects of both views, it remains important to balance innovative activities with appropriate protections for workers and consumers.

An important feature of on-demand economy platforms is the ratings and feedback mechanism that consumers use to rate providers,

Figure 5-iv
Chicago Taxi Medallion Transactions, 2011–2015



Source: City of Chicago, Business Affairs and Consumer Protection.

and that providers use to rate consumers. Without these feedback mechanisms, it would be very difficult for platform users to assess safety and propensity for fraud, which are often governed by regulations in traditional businesses that do not always extend to on-demand economy firms. Ratings and feedback mechanisms do very little, however, to promote basic labor standards for people performing the work, another important purpose of regulation. These ratings mechanisms and other user information collected by on-demand economy platforms also pose privacy concerns that are not yet fully understood.

As of 2014, slightly more than three-quarters of American households had adopted Internet in the home.[11] Non-adopters cite cost, availability in their communities, and perceived relevance as reasons to forego a broadband subscription.[12] There is substantial variation in broadband access across income groups. One way to visualize the digital divide is to consider the relationship between Internet use and household income across different areas of the entire United States. In Figure 5-17, each dot represents a single Public Use Microdata Area, or PUMA, all of which are constructed by the Census Bureau so that they contain roughly 100,000 residents.[13] The graph displays the share of residents in each PUMA who report using Internet in the home against median household income for that PUMA.[14]

Figure 5-17 shows a strong positive relationship between home Internet adoption and median income (Council of Economic Advisers 2015b). The wealthiest PUMAs tend to have home Internet adoption rates in excess of 80 percent, while the least well off PUMAs have adoption rates of 50 percent or below. Admittedly, higher income might lead to more Internet use, or vice versa, or there may be a third variable, such as education, that

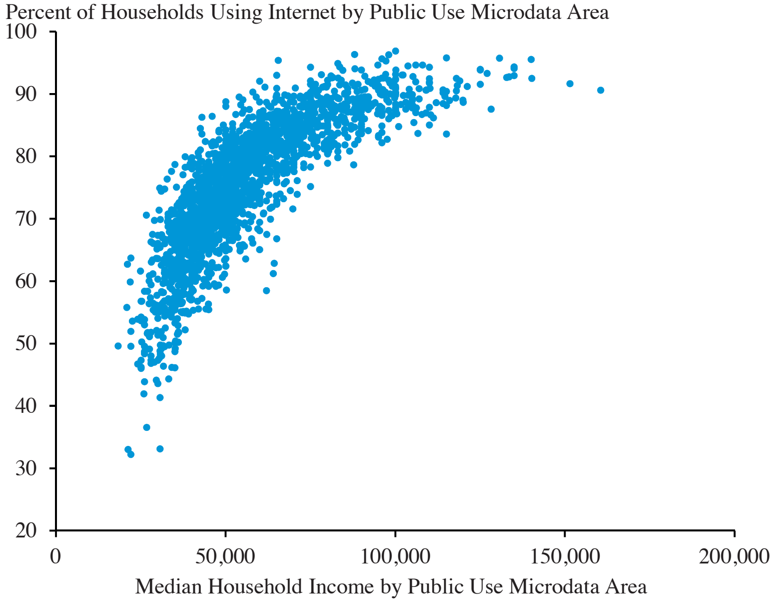
[11] These data come from Census' 2014 American Community Survey. The relevant question is worded such that the respondent is not asked to differentiate between wireline as opposed to wireless access. Exact question text appears below in footnote 14.

[12] Data on the reasons for non-adoption are from the Current Population Survey, as tabulated by NTIA in its "Digital Nation" reports series.

[13] PUMAs are geographic areas defined for statistical use. PUMAs are built using census tracts and counties, nest within States, contain roughly 100,000 residents, and cover the entire United States. For more information on Figure 5-17, as well as other statistics on the digital divide, please see CEA's 2015 issue brief "Mapping the Digital Divide", available at: https://www.whitehouse.gov/sites/default/files/wh_digital_divide_issue_brief.pdf

[14] The specific question used to calculate the share of households using the Internet was the following, "At this house, apartment, or mobile home—do you or any member of this household access the Internet?" Thus, CEA does not include householders that only access the Internet at a public location, such as a school or library, in our measure of Internet adoption. Following the convention that Census uses in its public reports on computer and internet use, group quarters are excluded from these estimates, and a household is only counted as having internet access if it reports having a subscription.

Figure 5-17
Household Income and Home Internet Use, 2014



Source: Census Bureau, American Community Survey (2014); CEA calculations.

correlates with both outcomes. Keeping in mind these concerns about causal inference, a linear regression suggests that doubling a PUMA's median household income is associated with a 20.2 percentage-point increase in the expected rate of Internet adoption as of 2013 (Council of Economic Advisers 2015b).[15] Moreover, the fact that nearly all Americans live in communities where basic Internet service is available strongly suggests that income disparities play a dominant role in explaining this relationship. Thus, it does not appear to be the case that telecommunications firms are systematically choosing not to offer any form of Internet infrastructure in lower-income communities. It should be acknowledged, however, that the quality of Internet service available varies substantially, with more than one-half of the population lacking access to download speeds of 25 Mbps or greater as of 2013, often in rural or tribal areas (Council of Economic Advisers 2015b; Beede 2014).

Closing this digital divide will allow more Americans to access the opportunities afforded by the Internet, such as online job search and better educational opportunities (Stevenson 2008; Fairlie 2004). For example,

[15] If home computer use is examined rather than home Internet use, the overall pattern is very similar (although average computer adoption rates are higher (most so for the poorest 20 percent of households), and regression estimates suggest that doubling median household income is associated with a 19.3 percentage-point increase in the probability of having a computer at home.

Kuhn and Mansour (2014) find that unemployed workers who search online for work are re-employed 25 percent faster than comparable workers who do not go online. More recent innovations, such as the on-demand economy platforms, require workers to be connected to the Internet, either via mobile or wireline, so as to sell their goods via a platform such as Etsy or Ebay, or to sell their labor services via Taskrabbit, Lyft, or Uber. Thus, reducing the digital divide not only enables more Americans to take advantage of Internet for educational, health and other needs, it also enables more Americans to access jobs and other employment opportunities.

To address these issues, the Administration has undertaken multiple initiatives to make sure that all Americans can benefit from new technologies, a topic that was covered in detail in Chapter 5 of the 2014 *Economic Report of the President*, and that has gained momentum in 2015. Since 2009, the public and private sectors have together invested more than $260 billion into new broadband infrastructure. Investments from the Federal Government alone have led to the deployment or upgrading of over 110,000 miles of network infrastructure. At the same time, 45 million additional Americans have adopted broadband. In January 2015, the President announced concrete steps that the Administration would take to ensure fast and reliable broadband is available to more Americans at the lowest possible cost. Chief among these efforts is the promotion of community-based broadband, which includes a call for State and local governments to roll back short-sighted regulations that restrict competition. In March 2015, President Obama signed an Executive Memorandum creating the Broadband Opportunity Council, an interagency group comprised of 25 Federal agencies and departments. The Council was tasked with promoting broadband deployment, adoption, and competition. On September 21, 2015, the White House released a report from the Council outlining steps that agencies will take to make additional funds available for broadband deployment, eliminate barriers and promote broadband adoption. Also in 2015, the Department of Commerce's NTIA announced its Broadband USA initiative focused on empowering communities to expand their broadband capacity by providing technical assistance. And in July 2015, the U.S. Department of Housing and Urban Development unveiled Connect Home, a new initiative involving communities, the private sector, and the Federal Government, designed to expand high speed broadband to more families across the country. The pilot program launched in 27 cities and one tribal nation and will initially reach over 275,000 low-income households, including 200,000 children. Finally, the President's ConnectEd initiative is on track to connect 99 percent of American students to high-speed broadband in their classrooms and libraries by 2018. Data show that the connectivity gap has been cut by about half since ConnectED was launched in 2013, with 20 million more students and 1.4 million more teachers now having access to fast broadband.[16]

Reducing the digital divide is critical: it ensures that all Americans can benefit from new technologies and innovations; that more Americans find jobs for which their skills are a good match; and that more Americans are able to start new businesses and reach a larger customer base. Reducing the digital divide therefore may be one way to address the long-term downward trend in business dynamism and worker mobility. These new businesses in turn compete with established firms, driving the cycle of competition and innovation that is so vital to productivity growth.

Conclusion

Productivity growth is important for all Americans because it can lead to higher wages and a higher standard of living. Technology and innovation are key ingredients for productivity growth. New technologies and innovations help firms to produce products and services more efficiently, and also lead to new products and services that are valued by consumers.

For these reasons, this Administration has made, and will continue to make, increasing American productivity and innovation a top priority. These initiatives take on a variety of forms, including patent reform efforts to guarantee that the fruits of innovation go to their rightful recipients. Additionally, spectrum policies have played a key role in promoting innovation, including spectrum sharing, the dedication of spectrum to foster safety and mobility in next generation vehicles, incentive auctions, which re-allocate spectrum to its highest economic value use, and the Administration's pledge in 2010 to make available up to 500 MHz of Federal and non-Federal spectrum over 10 years in order to enable licensed and unlicensed wireless broadband technologies. Finally, international trade agreements like TPP and T-TIP also promote the flow of ideas, increase access to markets, promote competition, and increase specialization in R&D. The Administration's entrepreneurship initiatives—such as "Startup in a Day"[17] —are designed to lower the barriers to starting and scaling a new company for all Americans. Aspects of the Administration's proposals for business tax reform would reduce the effective tax on manufacturing to no more than 25 percent, at the same time encouraging R&D and use of clean technologies. Similarly, Chapter 6 in this *Report* covers in more detail how the Administration's

[16] These data are available through Education Superhighway's 2015 State of the States report, available at http://stateofthestates.educationsuperhighway.org/

[17] For more information about Startup in a Day, go to: https://www.whitehouse.gov/blog/2015/08/04/startup-day-four-things-you-should-know

infrastructure priorities would make sure that the supportive environment for innovation is as complete as possible.

The Administration's latest *Strategy for American Innovation*, released in October 2015, details three key areas of investment that the government can pursue to ensure that the United States retains its innovative edge in the decades to come by: 1) continuing to invest in Federal R&D and other building blocks for future private sector scientific and technological breakthroughs; 2) advancing Federal efforts in national priority areas like precision medicine and advanced manufacturing; and 3) improving the Federal Government's capacities for innovation.

Promoting productivity and innovation in the aggregate, however, is not enough. Beyond closing the digital divide and improving education in STEM, other policies such as the Affordable Care Act (ACA), Earned Income Tax Credit (EITC), and raising the minimum wage all have a role to play as well. The ACA has the potential to allow prospective entrepreneurs the flexibility to pursue creative ideas and found their own businesses, since their health care insurance is no longer tied to their employment. The EITC helps insure that low-wage workers are rewarded for their work, boosting incomes of millions of American families, and allowing for more Americans to share in rising prosperity. A higher minimum wage helps workers to increase their share of the productivity growth. These and other policies pursued by this Administration help insure that America will continue to enjoy high productivity growth and that all Americans will share in the gains from this growth.