COUNCIL on FOREIGN RELATIONS

Renewing America

Progress Report and Scorecard

Keeping the Edge

U.S. Innovation

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Keeping the Edge: U.S. Innovation

INTRODUCTION

The United States outperforms its peers in technological innovation, which drives rising living standards in rich countries that are already at the cutting edge in inventing and adopting technology. Although China and some other developing countries are ramping up research and development, and are graduating many more scientists and engineers than a decade ago, they remain far behind the United States in combining innovation quality and quantity. But the challenges are growing, particularly when it comes to scientific research whose full benefits are not usually felt until decades later. Such research is essential for keeping the United States at the technological frontier, and it is also where the government has the most critical role. Addressing gaps in U.S. innovation policy could help ensure that the United States remains the leading innovation center for decades to come.

A successful innovation system is a complex web that requires substantial investment and brings together business, universities, and human capital. Few countries are seriously challenging the United States in any of those areas in quality or scale. U.S. government policy, though not without flaws, deserves credit for creating a nurturing innovation environment and for directly promoting innovation where the private market cannot. The U.S. government is relatively generous in supporting research funding for business and, unlike European governments, relies more on direct subsidies instead of tax incentives, which helps the smaller start-ups that disproportionately drive innovation. Big defense R&D budgets and government procurement also spur innovation in ways that no other country has matched. Recently, President Obama has focused new efforts on bolstering advanced manufacturing and clean energy, two areas where the United States could be performing better.

The United States also has an entrepreneurial culture, a limited regulatory regime, a developed venture capital industry, and a continent-wide single market, all of which gives U.S. businesses an edge at commercializing innovations. U.S. companies are especially successful in the global information technology (IT) market, and technology-intensive industries form a larger share of the economy of the United States than the economies of its peers. It has top-notch universities that produce more of the highest-quality scientific research than any other country, and a science and technology workforce that recruits the best foreign talent.

Yet a number of weaknesses should concern U.S. policymakers. Current trends point to a future of fewer scientific breakthroughs and less transformative innovation. Over time, U.S. businesses have been investing less in basic scientific research with distant market relevance, academics have been doing more "sure thing" research instead of high-risk but potentially high-return studies, and the public universities where most scientific discoveries take place are under historic financial pressure.

Federal policies could be improved in the following areas:

- The federal government should be increasing basic research funding at least in equal proportion to the amount the private sector has been cutting basic research funding. The federal government had increased funding for many years, but funding has remained flat for a decade.
- R&D incentives should be better targeted away from older established firms and toward young firms.
- Research expenditures should be rebalanced among the sciences. The life sciences currently receive twice as much federal funding support as all the other sciences, including engineering, physics, and computer science.
- Patent property lines for IT should be made clearer and so-called patent trolls reined in.
- The immigration visa system should do more to help employers attract the top scientific talent from around the world.

INNOVATION AND THE ECONOMY

In advanced economies, innovation is an important driver of economic growth and rising living standards. Growth comes either from adding labor and capital inputs—such as workers, the number of hours worked, worker education levels, and buildings and infrastructure—or by making these inputs more efficient or productive through innovation, which can be defined as new ideas, technology, or business methods. Rising living standards in developing countries such as India and China are driven less by innovation; these countries are still catching up to the developed world, increasing labor or capital inputs and adopting technologies designed elsewhere. But for rich economies already at the leading edge of technological progress, with slow-growing, well-educated workforces and modern infrastructure and buildings, innovation is more important for raising living standards further. It is at the heart of competitive advantage among rich countries.

Of course, Americans do benefit from innovations that occur elsewhere. The benefits of medical research, for example, transcend borders. So do breakthroughs in clean energy technology that may mitigate climate change. The United States has borrowed, improved, and commercialized plenty of technologies that were invented elsewhere; British inventors such as Alan Turing laid the foundation for modern computers, but it was Americans who fashioned computers into a profitable product. Similarly, Asian countries are adopting, manufacturing, and profiting from technologies first invented in the United States, such as semiconductors. A smart innovation strategy should include adopting and improving on innovations that occur elsewhere, as well as being the first to invent. Those who invent first get the first crack at making money from their inventions with the resulting business profits and well-paying jobs.

Some innovations are novel products that push the technological frontier forward, such as personal computers and cellular phones. Some are incremental improvements on existing products, where computer chips become faster or cellular phones become "smart" with Internet access and a touchscreen. Innovations can also be new processes, such as Dell's global supply-chain model where each computer is made to order for each customer rather than manufactured in bulk and held in stock for an order, which dramatically lowered expensive inventory holdover times. These innovations all enhance productivity.

Invention is only the first step in the process. Transforming an idea into a practical application for consumers is where innovation adds the most value to the economy. In other words, scientists and researchers are at the beginning of the innovation pipeline; businesspeople and entrepreneurs then figure out the best way to turn inventions into profit. This pipeline can take decades from beginning to end, and the end point is often initially unclear. For example, the computer was invented in the

1950s, yet it was not until the 1980s and 1990s that the digital economy began to take shape.

Young firms or start-ups are usually better at breakthrough innovations, especially in immature industries, which offer more room to grow.[1] Examples include Uber for ride-sharing or Amazon in the early days of online retail. Unlike larger firms, entrepreneurs are not bound by more rigid corporate institutions or an existing customer base. Large firms have always spent the majority of the country's business R&D funding, but these established firms tend to excel at incremental innovation.

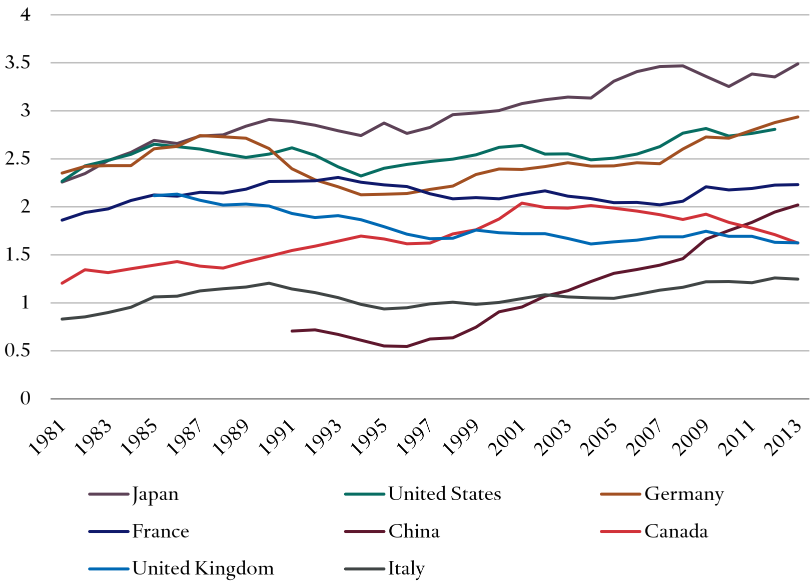
WHERE THE UNITED STATES STANDS

The United States stands out as a leader in technological innovation, but the landscape is becoming more crowded. Although no rule of thumb is in place for how much governments should be spending on R&D, major Asian economies, including Korea, Taiwan, and Japan, devote a significantly larger portion of their gross domestic product to it than the United States does. Sometime around 2020, China will likely surpass the United States as the world's biggest R&D spender.[2] Although their academic standards may not be as high, China and India are churning out science and engineering graduates at a pace that the United States could not hope to match, given a population one-quarter their size. China is also positioning itself to become a leader in some emerging areas of scientific discovery like the human genome. Yet these challengers still remain far behind the United States in combining innovation quantity with quality.

R&D FUNDING OVERALL: THE UNITED STATES IS NEAR THE TOP

The United States, as a whole, spends the most on R&D in absolute terms and also more than most wealthy countries on R&D relative to GDP. At 2.8 percent of GDP, U.S. national R&D expenditures are currently higher than at any time since their peak in the early 1960s, when the costly U.S. space program took off. China has made rapid gains, albeit from a much lower spending base. Among G7 countries and as a percentage of GDP, only Japan has consistently outspent the United States on R&D (see figure 1). Scale and absolute spending

FIGURE 1. NATIONAL R&D EXPENDITURES AS A PERCENTAGE OF GDP (2000–2013)



Source: OECD Main Science and Technology Indicators (2015).

levels matter, too, and here U.S. spending dwarfs every other country. The United States still spends twice as much in absolute terms as the second-highest spender, China.

The makeup of U.S. R&D spending has shifted over time. In the 1960s, the government was responsible for two-thirds of national R&D, and businesses most of the rest. Now the shares have flipped: businesses make up two-thirds of R&D spending decisions. Across the wealthy world, businesses now outspend governments on R&D.

Businesses are closer to the market and therefore usually better positioned to decide the most efficient ways to allocate R&D dollars for the economy. But businesses tend to invest in ways that help their bottom line instead of what might be most beneficial to society. The bulk of business R&D is geared toward applied, or practical, research and especially development, which readies a product for the market.

Government funds are critical for basic research, which tackles fundamental scientific questions in fields such as particle physics or astronomy. This research often has long-term value for society but may not have much immediate market value. About one-sixth of all U.S. R&D goes toward basic research, a share that has held steady for three decades. Although data is poor, the United States appears to be devoting a higher share of its R&D resources to basic research than most G7 countries.[3]

U.S. CORPORATE LEADERSHIP IN ADVANCED INDUSTRIES

U.S. corporations have been highly successful in the global marketplace in those industries most associated with innovation, such as IT. Private-sector performance is one good way to assess a country's innovative prowess, because the market should reward new technologies that consumers want and business methods that are most effective.

U.S. businesses are strongest in industries where innovation plays a large role—in IT (e.g., Apple, Google, Microsoft), pharmaceuticals (Pfizer, Merck), financial services (JPMorgan Chase & Co., Wells Fargo), and industrials (General Electric, Boeing).[4] A greater share of the U.S. economy is knowledge-based (meaning industries linked to science and technology) than any other economy, and the share is growing faster than that of its peer competitors.[5]

In business management, which is important for incremental innovation, the United States outperforms as well.[6] U.S. firms invest more in IT management strategies and are more effective at extracting productivity gains from IT than non-U.S. firms.

Among the world's publicly traded firms, U.S. businesses are gaining ground. With U.S. businesses taking the lead in high-growth and innovative sectors, U.S. companies are taking over more of the top spots in the global marketplace even as the U.S. share of the global economy has declined over time (see table 1).[7] California-based Apple is the world's most valuable publicly traded company, having quadrupled its market capitalization since 2009. In market capitalization rankings, U.S. companies have become more dominant. Of the top one hundred publicly traded companies in 2014, forty-seven were U.S.-based, up from forty-two in 2009. Overall, European business rankings have been flat while Japanese and Chinese businesses have fallen.

U.S. business R&D also continues to expand. Of the top two thousand corporations that spend the most on R&D, the U.S. share has risen slightly while European and Japanese shares have been decreasing (figure 2). According to a recent business survey, the average U.S.

TABLE 1. MARKET VALUE OF TOP ONE HUNDRED GLOBAL FIRMS, BY COUNTRY OF ORIGIN

	2009	*2014*
United States	45%	54%
Europe	27%	27%
Japan	4%	2%
China	15%	8%
Other	8%	9%

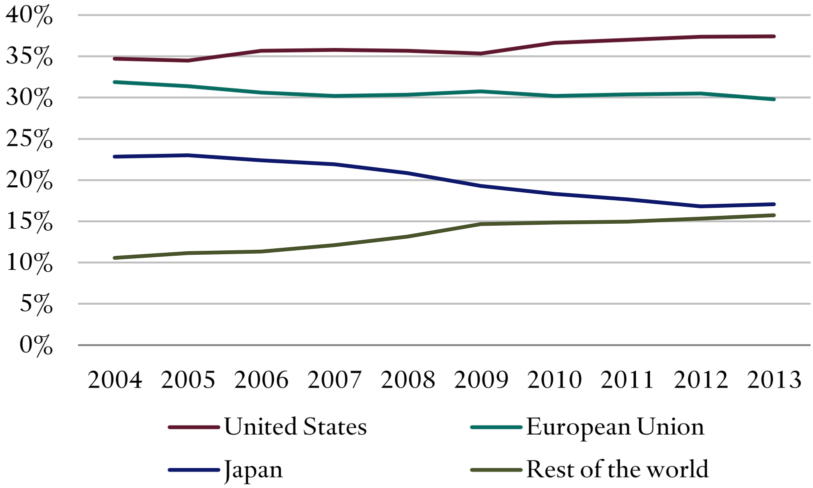
Source: PwC, Top Global 100 Companies (2014).

corporation planned to boost research spending in 2015 by nearly twice the rate of its international competitors.[8]

Better entrepreneurial climate. Although many top U.S. companies are global in terms of operations and revenue, they all benefited from a start-up launching pad in the United States that is among the best in the world. It is easier to take business risks and try something new in the United States because bankruptcy laws are more forgiving to business failure, it is easier to hire and fire workers, and capital markets are deep and broad. The United States consistently ranks among the easiest places in the world to do business, and its regulatory barriers to start-ups are among the lowest.[9] All these factors are strongly correlated with more knowledge-intensive and innovative economies.[10] This regulatory environment may be a big reason why U.S. firms grow and contract more quickly than European firms, a process that enhances efficiency and productivity.[11] The U.S. economy is also better at allocative efficiency—channeling the best workers and resources toward the most innovative and productive firms.[12]

U.S. start-ups benefit from highly developed venture capital and angel investing industries. They give seed money to start-ups, most of it in information and biotechnology industries, and investors offer their business acumen to steer start-ups toward success. The U.S. venture capital industry has grown from $1 billion in 1980 to more than $100 billion today. Except for Israel, venture capital industries in other countries are tiny and mostly rely on public funding because private sources have been less willing to participate.[13]

FIGURE 2. GLOBAL R&D SHARES OF TOP 2,000 R&D-INVESTING FIRMS, BY COUNTRY OF ORIGIN (2004–2013)



Source: EU Industrial R&D Investment Scoreboards (2005–2014).

Americans appear more culturally inclined than their peers to take business risks, too. Some economists describe Americans as adventurous consumers, giving innovators more room to experiment with new products.[14] Compared to their international peers in surveys, American entrepreneurs display more confidence in their abilities and less fear of failure, signal greater intention to hire new staff, and produce more innovation by offering novel products or services.[15]

Less private-sector basic research. U.S. businesses are devoting less of their R&D budgets to long-term basic research than in the past.[16] This is especially true of corporate technology firms, which in the 1960s and 1970s supported giant in-house research labs, including the legendary AT&T Bell Labs and Xerox PARC. Google and Microsoft still do this kind of research, but it is a smaller slice of their R&D spending compared with the big technology firms of the past. Business R&D has indeed exploded in recent years, but the growth has been almost entirely focused on the development of products for immediate market opportunities rather than the research to invent new products. From a profitability standpoint, this shift makes sense; in the 1980s, corporate returns on basic research began to decline, so corporations allocated their resources elsewhere.[17] The same is happening with venture capital, which is shifting toward less risky (e.g., software instead of capital-intensive hardware) and shorter time-horizons (e.g., later-stage instead of seed-stage) projects.

Shift in research to smaller firms. Although corporations are investing less in their own long-term innovative capacities, they are increasingly willing to buy inventions developed by other, usually smaller, firms with highly specialized scientific research niches.[18] Silicon Valley firms such as Facebook are buying out start-ups like WhatsApp rather than competing by developing in-house products. Although small firms in the U.S. economy are less numerous than in the past, they are bearing more of the R&D burden than ever.[19]

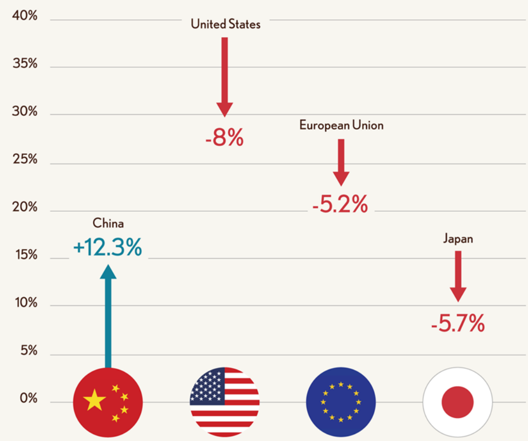
This evolving research hierarchy may make more market sense. Smaller firms have a track record of conducting more cost-effective R&D, claiming more lucrative patents, and taking up much of the slack left by the overall relative decline in corporate research compared to development.[20] But small firms are unlikely to fill the basic research gap. These businesses have more immediate profit concerns and can make more money by pursuing patentable applied research.

More business R&D going abroad. U.S. corporations are also shifting more of their research and manufacturing abroad, which could lead to less innovative capacity within the United States. More than 80 percent of U.S. business R&D funding is still spent in the United States, but that share is gradually falling. For decades, U.S. corporations have been increasing R&D investment abroad at twice the rate of investment at home. This could lead to a hollowing out of the innovation infrastructure within the United States, weakening the network of innovative researchers and start-ups.

This location debate is most developed when it comes to trade in consumer electronics. Although the consumer electronics supply chain is now almost entirely based in Asia, most of the value of high-end goods comes from the design process (for example, at Apple headquarters in Cupertino, California) rather than the final assembly (in China). But at a certain point, the production—with all the tinkering and expertise honed on and around the manufacturing floor—could pull innovation activity and capacity away from the design headquarters. In a classic

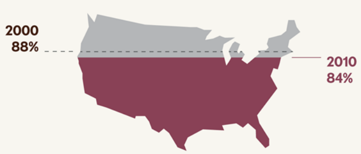
Keeping the Edge
U.S. Innovation

Research Spending Growing Overseas

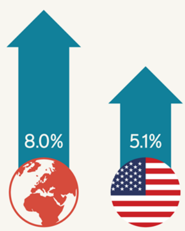


Change in percentage share of global R&D expenditures, 1996–2011

With the rise of China, the U.S. share of global R&D is falling.



Share of U.S. multinational R&D in the United States



U.S. multinational R&D annual growth rate, by location

Although U.S. multinationals still mostly invest in the United States, that share is declining, which might mean more innovation potential is leaving the country.

case, the initial offshoring of consumer electronics production in the 1980s to Japan, South Korea, and Taiwan then turned into dominance decades later in the design and production of lithium-ion batteries and flat-screen panels. And more than most peer countries, the United States has been losing ground on manufactured high-tech exports as a percentage of total U.S. exports.[21] France and Germany, meanwhile, have seen their high-tech export shares increase. More trade competition may also mean less U.S. business innovation; for example, U.S. firms in sectors that face the most Chinese import competition spent less on R&D and patented less often.[22]

TOP-NOTCH RESEARCH UNIVERSITIES

If the United States is dominant in innovative industries, it is even more dominant in academic research. U.S. research universities play an indispensable role in the U.S. innovation system because they conduct the majority of the country's basic research. The most innovative, entrepreneurial regional clusters in the United States—in Silicon Valley and the Route 128 corridor outside Boston—grew around existing elite universities.

The quality of U.S. research is unrivaled. Many other countries are investing heavily in creating academic research systems; the number of academic publications coming from outside the United States, and particularly from China, is growing rapidly. Yet when comparing citations, which can be a good proxy for research quality, U.S. articles have been concentrated in the top percentiles across all scientific fields for decades, European articles in the middle, and Japanese ones toward the bottom. China is making gains in quality, but not at the highest level.[23] The same goes for university rankings by research quality; U.S. universities occupy sixteen of the top twenty spots when ranked by citations.[24]

U.S. universities are also better at monetizing their research. To be sure, only the elite universities—for example, Harvard, Massachusetts Institute of Technology, and Stanford—make big profits. And direct university spinoffs into successful companies have been rare, the major exception being in the emerging biotechnology industry, where hardware-intensive university labs have given spinoffs a leg up on the competition. But no other country has universities that exploit their research for profit as effectively as those in the United States do.[25] Many

European countries are adopting U.S.-style regulations in the hopes that their universities can make U.S.-level profits.[26]

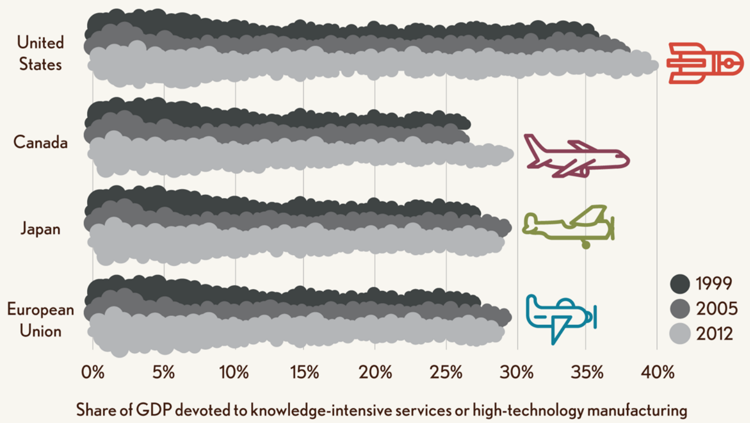
The U.S. university system is organized—with decentralized and autonomous administration, diversity, and competition-based funding—to promote research productivity and innovation.[27] University resources are more diversified in the United States, the money coming from institutional endowments, public coffers, and private donors. In many other countries, university systems are centrally administered by the government and funding is apportioned based on formula rather than merit. European countries have tended to rely more on bureaucratic national research institutes instead of universities to carry out basic research. Europe has been trying to move closer to the U.S. model, downsizing national research institutes and decentralizing university systems. One natural endowment also gives the United States an edge—a single-language academic market for U.S. researchers and publications. Only China can claim the same scale for its academic community.

Growing risk aversion in academic basic research. Yet such intense competition, coupled with more demands from funders for results, could be making U.S. academic research more risk averse.[28] The federal government has become more vigilant about funding accountability, attaching shorter review cycles and more deliverable requirements to research grants. Because success rates for winning federal grants have been on the decline for decades, researchers are more likely to propose research ideas that are less risky and more likely to succeed. Private and philanthropic funders, who have become larger factors in academic research, are also more exacting about results. This could make transformative innovation less likely. According to one analysis, funding schemes that reward early failure and long-term over short-term results produce more outside-the-box and high-impact research.[29] And, perhaps, as a result of choosing more research with guaranteed results, federal grants are increasingly being rewarded to older, established researchers. These scientists tend to produce less transformative scientific discoveries, whereas young researchers have more difficulty getting a start.[30]

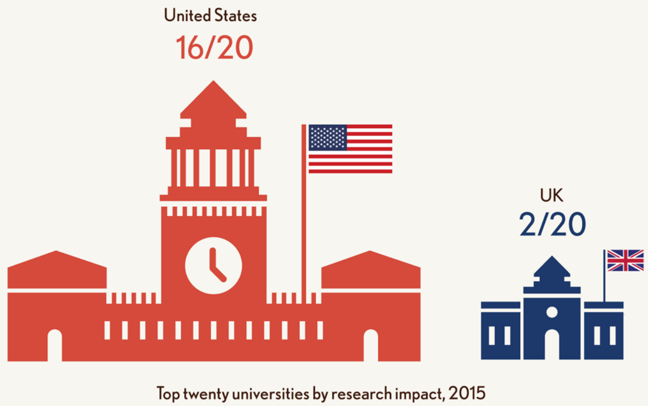
Currently well funded, but a financial squeeze is coming. The United States spends generously on its universities and, until recently, university R&D funding had been increasing steadily for decades. On a

Keeping the Edge
U.S. Innovation

Dominant in Quality



The U.S. economy is more knowledge-intensive than its competitors and no one is catching up.



The United States has the most high-quality research universities.

per-student basis, only Canada devotes more resources to its higher education system.[31] Going back to the early 1990s, the university R&D expenditure growth rate has outpaced that of business R&D.[32] Between 2000 and 2010, universities increased their R&D expenditure budgets by one-third, with federal funding boosts accounting for most of that increase.

But university research funding has been under pressure. Many state governments have been cutting back on their general support, although some universities rely much more on public funding than others. Elite private universities with deep-pocketed endowments will be fine. But for public universities doing first-rate research—such as the University of California, University of North Carolina, Ohio State University, University of Texas, Texas A&M, University of Washington, and University of Wisconsin—any institutional funding squeeze would affect research programs. Public universities like these conduct most of the country's academic basic research and graduate the majority of students with advanced degrees who go on to do further innovative research. However, reductions in federal spending required under sequestration and discretionary spending caps could precipitate further budget cuts for university research.

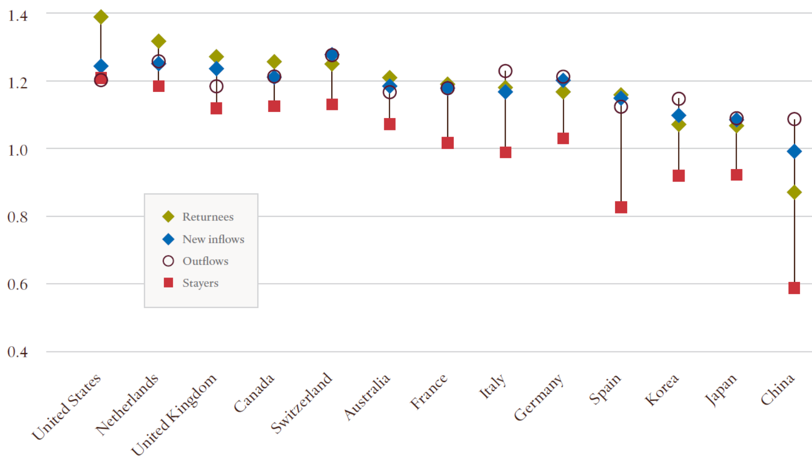
HIGH-QUALITY HUMAN CAPITAL

Human capital has historically been the most critical component driving economic growth, and here again the United States comes out on top.[33] Compared with other countries, a larger percentage of U.S. workers are researchers.[34] Although U.S. K–12 students do not perform especially well on international math, science, and technology tests, the U.S. adult workforce produces a disproportionate share of scientific breakthroughs, and these researchers are paid handsomely compared with their peers. Across the public, private, and nonprofit sectors, American scientists earn about one-third more than European scientists—more than in any other rich country when adjusted for cost of living.[35] The impact, measured by number of citations, of U.S. scientific authors is higher than anywhere else in the world.[36] The United States is also home to 60 percent of Nobel laureates, and the share continues to rise.

STEM professionals and technology entrepreneurs are disproportionately foreign born. Much of American innovation talent is foreign born. If it were not for foreigners, the U.S. Nobel Prize rankings would look markedly different: roughly 30 percent of U.S. prizes go to foreign-born researchers. These researchers are especially concentrated among science, technology, engineering, and mathematics (STEM) fields. Foreign-born residents are one-eighth of the U.S. population but roughly one-half of STEM PhD students, most of whom end up staying in the United States.[37] They also tend to make more exceptional research contributions than U.S.-born researchers, perhaps because American universities attract the most elite talent from abroad.[38]

According to one measure, the U.S. innovation system seems to benefit the most from the international migration of scientists, compared to other countries in the OECD. Of the world's immigrant scientists, those who reside in the United States write the most widely cited scientific articles.[39] And U.S. scientists who study abroad and then return are much more likely to write influential articles than returnees elsewhere. Those U.S. scientists who do leave permanently are no more influential than the ones who stay, unlike in most other countries (figure 3). Another study that compared the United States and the United Kingdom, which is another top destination for immigrant scientists, found that the U.S. system pushed foreigners to reach their full potential more than the UK system.[40]

FIGURE 3. IMPACT OF SCIENTIFIC AUTHORS, BY CATEGORY OF MOBILITY (1996–2011)



Source: OECD (2013).

The United States is holding up well in the global competition for talent. There is some evidence that Chinese academics are heading back to China in greater numbers than they once did after a stint in the United States.[41] And stay rates for Chinese students, who are the largest group of foreign students in the United States, have declined some in the last decade. Still their rates are higher than for any other nationality—85 percent of Chinese students remain in the United States five years after completing their studies. Many other countries, including Canada, Australia, and the United Kingdom, are aggressively catering to the international student and skilled immigrant markets, making the United States slightly less competitive than it used to be for the average mobile student or professional.[42] Nevertheless, the United States is still the number one destination for nearly every country's emigrant scientists and STEM students, especially for those coming from emerging science powers India and China. The tide of foreign students and skilled workers is not ebbing even as countries like India and China grow more prosperous.[43]

The foreign born are also overrepresented in business clusters. Residents of the counties that make up Silicon Valley are 36 percent foreign born, which is among the highest in the country. Anecdotally, U.S. corporations are much more likely than European or Japanese firms to hire nonnative chief executive officers.[44]

FEDERAL INNOVATION POLICY

The success of the United States as an innovation leader suggests that the U.S. government is getting its innovation policy mostly right. Obama has focused new policy efforts in targeted ways to boost emerging advanced manufacturing practices (e.g., nano-engineering and 3-D manufacturing) and renewable energy research, both sectors with the potential for broad societal gains. Except for R&D tax policy, most rich countries are adopting U.S.-style policies. They are lowering regulatory barriers, making it easier to hire and fire people and to start businesses, and promoting regional technology hubs in hopes of developing their own Silicon Valleys.

But unlike the United States, these countries are also crafting formal national innovation strategies and tasking government innovation agencies to carry them out. In addition, they are generally more comfortable picking winners by using public funds to promote specific industries or applied technologies. This may reflect weakness on their part, but it also means other countries are ramping up their innovation strategies in an effort to erode the U.S. lead.

HOW INNOVATION POLICY WORKS

Innovation policy can be categorized along two dimensions. First, governments set the stage for innovation to develop organically. This would include, for example, the regulatory environment (e.g., patent law and standards for industry research and product testing) and developing human capital (e.g., immigration and education policy). Second, governments can play a more direct role by funding research through grants or tax breaks.

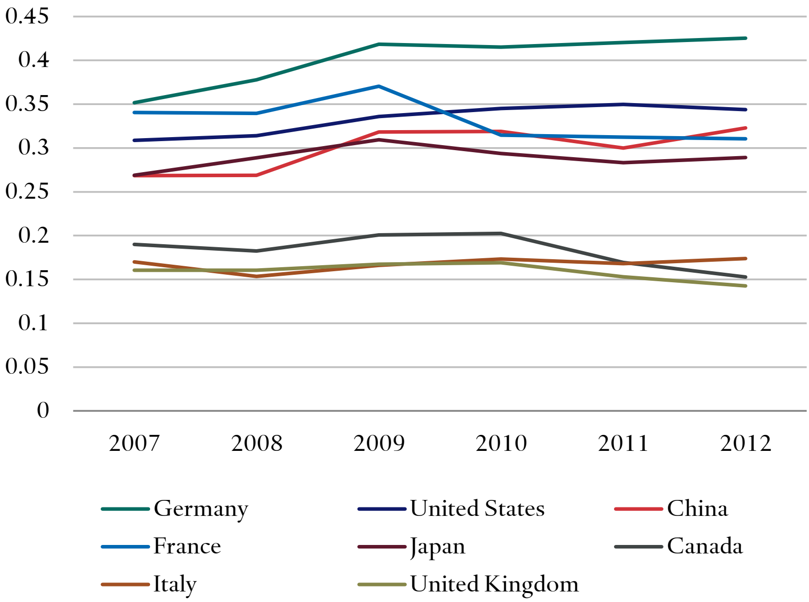
The challenge is to position policy so that business investments in innovation are enhanced rather than impeded or replaced. If government subsidizes a business to carry out research it would do anyway, the subsidy is a waste of public resources. If the government tries to pick winners by investing in applied research or product development that is too narrowly focused and misaligned with market signals so that no business could eventually earn a profit on its own, the investment can be a waste, too.

Government policy should find the sweet spot by funding research and innovation that is valuable to society but that the private sector would not undertake on its own. Private R&D has spillover benefits for the public that are not calculated into private-sector decisions. As a result, businesses do not invest in R&D at a level that would maximize social benefits.[45] A well-designed tax credit can promote private R&D broadly, without picking winners. Governments lead in funding basic scientific research because it generally cannot be protected by patents and the research's market value is too uncertain and distant for most firms to bear the risk. However, basic research also leads to advancements in general-purpose technologies like computers, biotechnology, or synthetic materials that have broader societal benefits.

FEDERAL R&D SPENDING LEVELS: GENEROUS, BUT UNDER HISTORIC PRESSURE

Compared with its peers, the U.S. federal government invests a lot of public dollars in R&D as a percentage of GDP (see figure 4).[46] The

FIGURE 4. PUBLIC R&D EXPENDITURES AS A PERCENTAGE OF GDP (2000–2012)



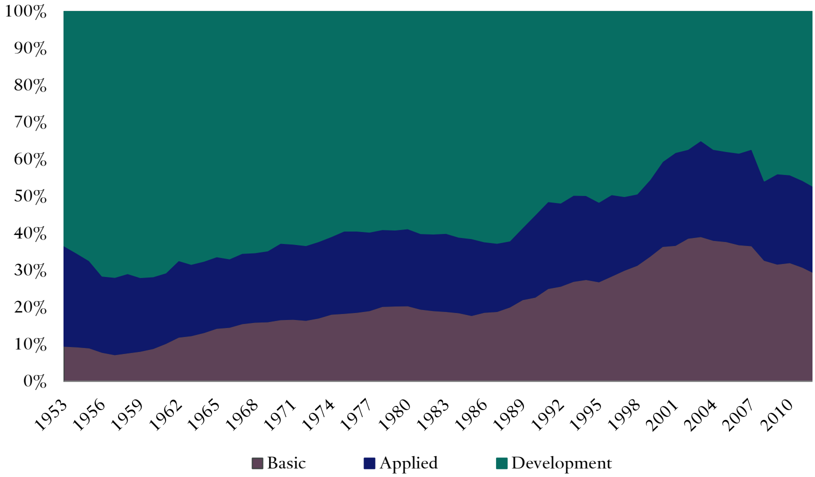
Source: OECD (2014).

same is the case for government R&D support for business, where only France spends more, as well as for basic research.[47] And whereas most other rich countries—including Canada, France, and the UK—slashed R&D spending during the difficult economic period between 2007 and 2012, the U.S. government increased it.

Until the mid-2000s, federal support for basic research—or more academic scientific research—enjoyed steady growth. Today, half of all federal R&D goes elsewhere, to more practical development (mostly for weapons systems). But government development budgets have been cut, especially since the end of the Cold War. Over time, federal R&D dollars increasingly targeted basic scientific research instead of defense-related development. Basic research was less than one-tenth of the federal R&D budget in 1950 (see figure 5). Now it is one-quarter.

The trends, however, began to reverse in the mid-2000s, with development spending boosts along with flat basic research funding. Yet R&D generally has remained a relatively resilient public budget

FIGURE 5. U.S.GOVERNMENT R&D FUNDING SHARE, BY CHARACTER (1955–2012)



Source: National Science Foundation (2015).

priority compared with other discretionary priorities, such as education or defense.[48]

It is hard to determine the optimal amount of government R&D spending, although government investments have clearly spurred innovation.[49] In a conservative estimate, 88 percent of the top inventions between 1977 and 2006 depended on publicly funded research.[50] Obama (along with most world leaders) uses a benchmark goal that national R&D should be 3 percent of GDP.

Spending still focused on defense. The U.S. government's R&D budget is still heavily oriented toward defense. Roughly half of U.S. government R&D spending goes through the Department of Defense. The UK allocates the next-highest proportion among OECD countries, with about one-third of its research budget spent on defense.

Defense R&D and procurement produce tremendous advantages for the U.S. innovation system even though the commercialization of defense research was never a deliberate policy goal. Many of the technologies that have made U.S. companies global powerhouses—the Internet, global positioning system, touchscreen displays, and voice-recognition software—were initially developed for military purposes. The beginning of the semiconductor industry, which gave Silicon

Valley its name and first technology boom in the 1950s, was almost entirely directed and financed by the Department of Defense. However, defense R&D may be producing fewer spillovers; innovations such as stealth technology grow increasingly specialized and have little consumer value. Nevertheless, defense procurement pumps a huge amount of money into technology research.

FEDERAL BUSINESS R&D SUPPORT FAVORS DIRECT SUBSIDIES OVER TAX INCENTIVES

The U.S. government uses direct subsidies more than tax breaks to promote business R&D. This is largely a sensible approach. But existing tax breaks favor older, established firms and could be better targeted at young and small firms that need financial help and are disproportionately innovative.

In the United States, tax credits amount to 22 percent of all federal business R&D support, compared with 50 percent in the UK, 70 percent in France and Japan, and 85 percent in Canada. In 1981, the United States was the first country to offer an R&D tax credit. Now, however, the U.S. credit is lower than most other countries except for Germany, which has no R&D credit at all. Additionally, most countries have been sweetening their tax credits over time; the United States has expanded its direct subsidy programs, instead.

Tax incentives versus direct subsidies. Tax breaks are not the most efficient way to promote business R&D, especially for start-ups. Tax breaks have certain advantages: they objectively apply to all qualifying R&D, they are easier to administer than grants, and they let the market decide where and how to allocate R&D, though these preferences are not always the most socially valuable. Empirical studies find that tax breaks may lead to some more business R&D spending, but not beyond what is lost in tax revenue, which is how economists typically compare credits and grants.[51] The United States uses an incremental tax credit, which applies to increases in R&D spending, and this form of tax break delivers slightly more business R&D than the volume-based tax credits favored by most European countries. Still, the U.S. credit does not deliver much more in extra R&D spending than in revenue losses.[52] Tax credits are also easily exploited by clever firms that find ways to bend legal language to qualify. Several countries known for their innovativeness, including Switzerland, Sweden, and Germany, do not even have an R&D tax credit.

The United States could do more to target tax credits toward smaller firms. It is one of only a few rich countries that applies the same R&D credit regardless of firm age or size. Other countries, including France, Canada, and the Netherlands, recently introduced R&D credits specifically for young firms. Small firms, which usually have slimmer profit margins, are more sensitive than large firms to any financial incentive.[53] The U.S. government could start by making the credit refundable. This allows companies with more precarious profit situations, which often include start-ups, to claim the tax credit even when they owe no taxes.

Fortunately, Congress made the tax credit permanent in December 2015. The U.S. R&D credit had previously relied on congressional extensions every few years. Worse, Congress usually missed the expiration deadline and had to retroactively allow companies to claim the credit. Although nearly all politicians supported a permanent credit in theory, budgetary gimmicks had stood in the way.

Direct grants are generally a better approach, even if most of these government programs are focused on fulfilling each agency's specific missions—that is, defending the country (Department of Defense) or educating students (Department of Education)—rather than the general goal of promoting innovation. Direct subsidies are more effective at stimulating business R&D, especially when there is a matching component that requires firms to invest their own money as well.[54] Grants also give governments the ability to direct resources to projects that are more socially valuable.[55] Although there may be a greater administrative burden and some danger of political manipulation, the application process is at least transparent and competitive.

Compared with tax breaks, direct grants are also more helpful for start-ups and small businesses with immediate cash-flow needs.[56] Money up front gets new businesses on their feet or aids them through a tough stretch. Businesses have to wait to collect tax breaks after R&D money has already been spent. Empirical studies confirm that direct subsidies tend to incentivize R&D, whereas tax breaks often work better for companies already carrying out R&D. Studies also suggest tax breaks favor established firms over new entrants, and countries that rely more on such breaks tend to have a less dynamic firm environment (i.e., fewer firm births and deaths, and lower growth) in

R&D-intensive industries.[57] Direct grants appear to be more neutral, favoring young and established firms equally.[58] Winning a government grant can even help young firms attract private investors as a sign of quality.[59]

BUSINESS R&D COMMERCIALIZATION PROGRAMS: MOSTLY EFFECTIVE AND STEADILY EXPANDED

Beginning in the early 1980s, the U.S. government created several programs to help small businesses, universities, and federal labs move their research into commercially viable products. The biggest (by funding allocation) is the Small Business Innovation Research (SBIR) program, which gives early-stage research awards to small businesses.[60] The aim is to help businesses bridge the "valley of death" between good research ideas and commercialization. The government acts as an initial investor in projects that are far from the market and therefore too risky for venture capital or other private investors. Federal agencies with substantial R&D budgets have to allocate 2.8 percent of R&D to the SBIR program, equaling about $2.5 billion per year in awards given out in three phases to roughly 6,500 small businesses.

SBIR is a significant force in the technology start-up scene. According to one estimate, the SBIR program supplies up to one-quarter of all early-stage technology funding.[61] Although venture capitalists and angel investors allocate more seed and early-stage funds in total volume, SBIR spreads its funds to more firms with smaller awards.[62] Many of the best-known technology companies, including Apple, Compaq, and Intel, received SBIR awards in the 1980s.

SBIR has been effective. SBIR firms are better at getting subsequent private investors, are more likely to patent, and outperform non-SBIR firms in the market.[63] The effect is strongest for the earliest phase of funding and for younger firms.[64] Only 3 percent of surveyed SBIR firms indicated they would have undertaken their projects without SBIR funding.[65] The program is politically popular and has been reauthorized relatively easily, most recently through 2017. Over time, the amount of R&D financed through SBIR and the average award size have increased. SBIR-type programs are spreading across the world, from China to Germany, the UK, and Israel.

In the wake of SBIR's success, the federal government has created many other commercialization programs for specific technologies and industries.[66] Many of the programs involving energy and manufacturing, however, take the government further down the research pipeline, away from basic and early-stage and toward applied research and development, where the government has not been as effective.[67] It is too soon to tell whether these programs are working well.

MORE INNOVATION CHALLENGES AND PRIZES

The federal government increasingly uses cash prizes to promote innovation; these have been a great deal for taxpayers because the social benefits vastly exceed government funding costs.[68] The prizes are at most only a few million dollars, and the competition energizes nongovernmental researchers and entrepreneurs to tackle socially significant problems. The Defense Advanced Research Project Agency (DARPA) launched its first "Grand Challenge" in 2004; whoever could design a driverless car that completed a desert course fastest would win one million dollars. No car managed to cross the finish line that day, and no one took home the prize money. The challenge, though, focused brilliant minds on driverless technology. A decade later, Google is close to mastering the technology and most major automakers are working on their own prototypes. Since then, DARPA-sponsored competitions involving humanoid robots and radio communications, among other fields, have multiplied.

Innovation prizes have taken off across the federal government. Legislation in 2009 made it easier for federal agencies to launch their own competitions, specific to their needs and missions, with awards ranging from a few thousand to several million dollars.[69] Since 2010, more than four hundred competitions have been launched with more than one hundred thousand participants.

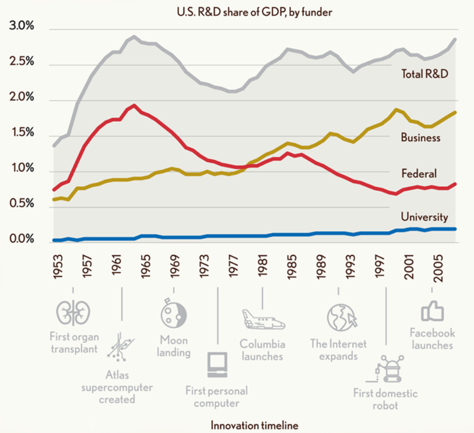
OBAMA'S MARK: ADVANCED MANUFACTURING AND RENEWABLE ENERGY

Obama has shifted federal resources toward two areas where the United States has historically lagged behind peer competitors: advanced manufacturing and renewable energy.

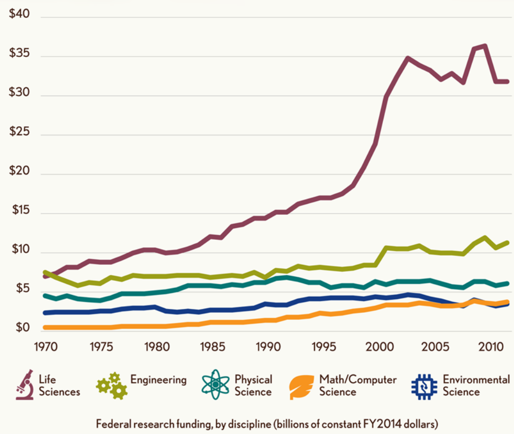
Manufacturing applied research institutes. Germany is the world's envy in advanced and high-wage manufacturing. The German government

Keeping the Edge
U.S. Innovation

Changing Domestic Priorities



While government R&D as a percentage of GDP has declined over time, business R&D has risen.



Federal research-funding priorities have become unbalanced, skewing toward the life sciences and away from the physical sciences.

invests heavily in a network of applied research institutes to support manufacturers. Germany spends 12.7 percent of its national R&D on industrial production and technology research; the United States spends less than 1 percent.[70]

As part of Obama's Advanced Manufacturing Initiative, the federal government is trying to build a network of Manufacturing Innovation Institutes (MIIs) using the German model. Although there were many federal applied research programs, none focused squarely on commercializing manufacturing technologies or scaling up new technology products for an entire industry.[71] Each institute specializes on a specific emerging technology and is situated in a regional hub, collaborating with universities and firms that are already best positioned to exploit the technology. By building domestic expertise in emerging manufacturing technologies, the hope is that more of the manufacturing will stay at home, too. The first MII, for 3-D manufacturing, was started in 2012 in Ohio. There are now others, including next-generation power electronics in North Carolina and lightweight, durable materials in Michigan. So far, eight MIIs are up and running, and the Obama administration is aiming for forty-five within ten years. Each institute must match federal funds from private partners. The institute in Ohio now has twice the private-sector contributions needed to match the federal amount, which suggests that participating firms believe the institutes are a good investment. Republicans have been supportive of MIIs and have agreed to fund them at Obama's requested levels.

It may be too soon to test the effectiveness of the institutes, but some detractors worry they are being used as regional economic development tools rather than smart innovation policy. An alternative or complementary approach could be a single national manufacturing research institute, modeled on the highly successful National Institutes of Health (NIH) and drawing expertise from across the country.

Clean energy. During the Obama administration, clean energy research has received the biggest budget boost of all R&D priorities, albeit from a relatively low base. Between 2005 and 2015, applied energy programs have seen a 50 percent funding increase, against 19 percent for general science.[72] Much of the research is carried out at Energy Frontier Research Centers—the energy version of the Manufacturing Innovation Institutes—which are also based on public-private partnerships and matching private financing. There is now also an energy version of

DARPA, the Advanced Research Projects Agency–Energy (ARPA–E), doing more ambitious energy research at the technological frontier.

New programs within the Department of Energy are working with the private sector to build solar panel production facilities, develop next-generation batteries for electric cars, and conduct biofuel demonstration projects, among other initiatives. Not all have proved profitable, and, arguably, too much public money has gone toward scaling up mature technologies (e.g., solar thermal power plants) rather than emerging technologies that may be more competitive with fossil fuels (e.g., next-generation solar photovoltaic technologies).[73] But Obama's clean energy push is the most serious federal effort to support clean energy innovation since the early 1980s.

The United States has long led the world in clean energy technology innovation—at least when measured by patents—but other countries, such as China, are leading the way in clean energy production and investment.[74] In the 1990s, for example, the United States used to be the top solar panel producer, with 45 percent of the global market share.[75] Today the U.S. share is less than 5 percent and China has a near monopoly. And whereas the United States had the highest annual investment in clean energy as recently as 2008, now China occupies the top spot, investing almost twice as much as the United States.[76] China added more renewable power capacity in 2014 than any other country.[77] China's massive spending spree in clean energy technology could cause the locus of clean energy innovation to shift away from the United States as well.

The benefits of clean energy technology are not just environmental. Business opportunities are huge in exporting clean technologies to giant markets like China and India, which only recently embraced clean energy. The technologies are also becoming more competitive with fossil fuels. For example, the cost of solar panels has dropped more than tenfold since 2000 and the rate of solar deployment has increased by the same factor in just seven years.

But the commercialization of innovation and deployment has not kept pace. New solar technology breakthroughs in U.S. universities and federal laboratories could enable cheap and lightweight solar coatings for diverse new applications, but to date most innovative U.S. start-up companies have failed to achieve scale. Absent success in commercialization of new technologies, the United States will lose out on fast-growing markets in clean energy.

Obama's clean-energy initiative faces considerable obstacles. Republicans are far less keen on supporting renewable energy research than on promoting U.S. manufacturing. And, unlike other emerging technologies in immature industries, the energy sector has stiff competition from extremely successful, established oil and gas companies.

RESEARCH FUNDING ALLOCATION: TOO SKEWED TO THE LIFE SCIENCES

The federal government allocates three times more money to the life sciences than to any other field of science. It has not always been this way. In 1990, federal allocations were roughly equal across the major science disciplines—life sciences, engineering, physical science, math, computer science, and environmental science. Beginning in the late 1990s, however, NIH funding for life sciences shot up and support for other sciences remained flat.

In principle, most presidents and both political parties have supported putting more public dollars into basic science research. President Ronald Reagan in the early 1980s was the first to pledge a doubling of science funding, a spirit that continued through to the late 1990s, when this was delivered to the NIH in a quick—perhaps too quick—jolt.[78] The 2007 America Competes Act authorized doubling funding over seven years, but only a fraction of the increase was eventually appropriated.[79] Obama entered office with the same doubling pledge, but has since backtracked under the strain of tight budgets. And in the era of sequestration, the non-life sciences are unlikely to see double funding any time soon.

The unbalanced science-funding priorities are difficult to justify.[80] The United States spends more on medical research than any other country by a large margin. As a percentage of GDP, the U.S. government spends much more on medical research than the average for the rest of the OECD.[81] All this money could solidify the U.S. position as the leading medical research nation, and indeed many global pharmaceutical companies are moving their research labs to the United States. But there is no reason to believe the medical sector is uniquely positioned to drive innovation in the future. Additionally, medical research has become less productive over time, every dollar of R&D on average producing fewer medical breakthroughs.[82]

Keeping the Edge
U.S. Innovation

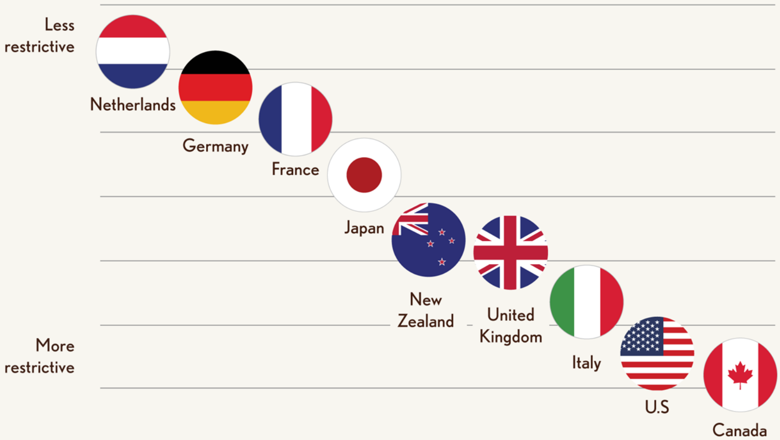
Policy Challenges

36%
Increase in patents granted

138%
Increase in patent-related lawsuits

2007–2011

Patent litigation is way up, suggesting the U.S. patent system could be functioning more efficiently.



Relative restrictiveness toward high-skilled immigrants, by country, 2012

The United States has a more restrictive immigration system for skilled workers than most other developed countries.

THE PATENT SYSTEM: OUTDATED AND PROBLEMATIC FOR INFORMATION TECHNOLOGY

The one-size-fits-all patent system is problematic for the IT sector in both hardware and software, where establishing inventor property rights is more difficult. This has led to a litigation morass and impedes IT innovation, with small firms and start-ups getting hit hardest.

Patenting incentives work for pharmaceuticals, not information technology. In theory, protecting creators' rights should encourage innovation. The creator incurs costs in time and money to come up with an invention. If someone else claims credit for those inventions in the marketplace, the value to the original inventor declines and there will be less invention. Empirical evidence suggests that, all else equal and in general, countries with stronger tangible property rights (e.g., land, objects) have experienced more economic growth.[83] The empirical evidence, however, for intangible rights like patents is not as clear.[84] The number of patents being filed and granted has risen sharply in the last thirty years, with no appreciable relationship to productivity growth. Property systems work better when the property and its owner can be clearly defined, and this is trickier for intangibles or complex technologies.

The patent system works best for pharmaceuticals. Protecting creator rights makes sense in this case, since companies spend huge amounts of resources to develop drugs. Protecting those rights is also relatively easy, since there is often only one patent for each drug, and each drug can be clearly distinguished from existing patented drugs. Most patent-related money is made in pharmaceuticals; life sciences account for only one-third of all patents but three-quarters of all patent profits. One empirical study found that the patenting system incentivizes innovation in the pharmaceutical and chemical industries.[85]

But the patent system is not working as well for software and IT, where the same study found disincentives. There is less need for patent protection; developing new information technology does not take decades of expensive tests. Property lines are fuzzy, and each innovation builds on previous innovations to form complex technological systems. Companies must navigate a "patent thicket" to get their products to market. The Apple iPhone, for example, uses 250,000 patents. Copyright faces similar problems—how to manage overlapping software codes, for example. Computer programmers have developed work-arounds through open-source code that is freely available online. Many in the software industry want to do away with intellectual property protections altogether. Yet the general trend over time has been to strengthen the status quo patent regime and inventor rights.

Rising patent litigation costs. Given so many IT patents where property lines are fuzzy, patent litigation costs have exploded. Some of the most high-profile patent litigation cases have involved Apple and Samsung, where each tries to claim broad swathes of technology such as smartphone physical design or automatic search functions. Between 2007 and 2011, the number of defendants tied up in patent lawsuits increased four times faster than the rate of patenting, and the vast majority of that growth involved software-related patents.[86] The average cost of each lawsuit is up, too, and increasing faster than business R&D spending. The defendants tend to be more innovative (measured by number of patents owned and R&D spending) than the plaintiffs doing the suing.[87] Studies have found that patent litigation is especially harmful to startups and small firms, whose litigation costs eat into R&D spending more than for larger firms.[88]

Too many patent lawsuits are frivolous and driven by firms that produce no products but do own and enforce patent rights. Nonpracticing entities accounted for half of all patent suits in 2013, up from 5 percent in 2001.[89] They are a problem mostly within the software industry, where they target smaller firms that cannot put up a fight.[90] Of all cases that have gone to court, only 2 percent of defendants have been found guilty. There may be a case for an intermediary patent market that allows inventors to sell and monetize their patents. But it is difficult to argue these nonpatenting entities are adding more to the innovation system than they are extracting in costs, especially given that they hurt small technology firms the most. According to one estimate, litigation costs may total as much as 20 percent of U.S. business R&D spending.[91] No other country has such costly patent litigation.

Some progress on patent trolls, less on fuzzy patents. Momentum is building in Congress to take on these so-called patent trolls. Obama and both parties have publicly expressed a willingness to make frivolous patent lawsuits harder. Legislation in 2011 took some initial steps, forcing patent-infringement suits to be launched against firms individually rather than collectively. The main patent reform bill currently before the House of Representatives proposes shifting the burden of litigation fees from defendants and forcing litigants to disclose more information early on in any legal action.[92] Additionally, some patent system tweaks could help start-ups by fast-tracking some patent applications. But Congress has made much less progress on fuzzy patents, which drive litigation costs and encourage patent lawsuits.

IMMIGRATION SYSTEM: NOT DESIGNED TO SELECT BY SKILL

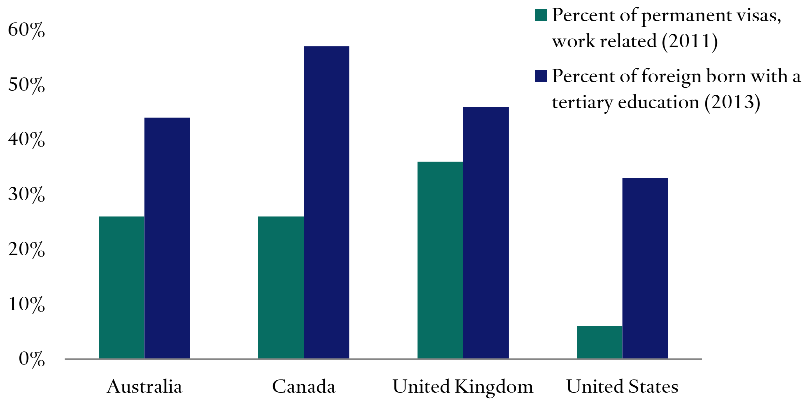
The United States is fortunate to receive much of the world's top talent despite an immigration system that does not prioritize talent. Under the 1965 Immigration Act that remains in force today, roughly two-thirds of permanent immigration visas are allocated to family members. Only 15 percent are awarded specifically for employment reasons. Exceptionally talented immigrants, such as elite scientists or athletes, have their own visa category, but only a small number qualify.

Highly skilled immigrants without such exceptional résumés face a more difficult problem. Their best bet is to enter the country as students and then marry Americans, which gives them permanent residency.[93] Foreigners who received their college degrees in the United States have a year (two for STEM graduates) to secure employment. Their stay in the United States is not guaranteed, however; their employer must file their application for a temporary work visa, typically the H-1B. The H-1B is capped at eighty-five thousand visas annually and does not adjust with employer demand.[94] In 2014, the limit was reached within a few days, triggering a lottery based on luck rather than qualifications. Employers must take on the several-thousand-dollar cost of applying, incurring the risk that even the most-qualified candidates might lose the lottery. The entire process can take over a year from initial filing before the employee can go on the payroll. Start-ups are at a disadvantage; they do not have the patience or resources to sponsor H-1B applicants, as Google and Microsoft do. The H-1B lasts six years, but the visa holder is usually tied to the same employer for that period. Adjusting from a temporary work visa to a green card normally takes several more years with the same employer. The waits are longest for Indian and Chinese citizens. They hold the majority of H-1B visas, but no one nationality can receive more than 7 percent of green cards each year, resulting in backlogs that can stretch a decade or more. This immigration system has barely changed in twenty-five years.

Other developed countries, meanwhile, have been changing their immigration systems to prioritize worker skills. No other country allocates such a high percentage of permanent visas for family reunification. Most allocate far more based on employment qualifications and have less restrictive skilled-worker immigration systems (figure 6).[95] Many countries, following the lead set by Australia and Canada, now use some combination of employer demand and points-based selection, where immigrants are ranked based on a number of factors—including job offers and skill levels—so that the most qualified are most likely to obtain visas. These countries can adjust the points system year-to-year depending on the needs of their economies rather than setting an absolute and inflexible cap. Moving from a temporary to a permanent work visa is also usually faster in other countries. In part because of their skills-focused immigration systems, the foreign-born in other English-speaking countries tend to be better educated than in the United States (see figure 6).

Congress has failed to make any significant changes to the immigration system even though there is bipartisan support for prioritizing high-skilled immigrants. Several bills have been introduced in recent years that would increase the H-1B cap or increase the number of permanent visas for skilled migrants. The effort, though, has so far languished because Congress has been unable to agree on comprehensive legislation that would address other immigration-related issues, such as border security, low-skilled immigration, and the legal status of unauthorized migrants.

FIGURE 6. SHARE OF PERMANENT VISAS FOR WORK AND FOREIGN BORN WITH A TERTIARY EDUCATION



Source: OECD (2014).

FUTURE PROSPECTS

There is a healthy bipartisan consensus on the importance of innovation and much agreement among Washington policymakers about where the problems exist. U.S. scientists and businesses are leading in innovation today and probably will be for the next decade. The challenge is preserving that lead. Where the United States is weakest today—businesses and scientists stepping back from risky but essential scientific research—is also where the government can play the biggest role in ensuring the United States remains dominant for decades to come.

Endnotes

1. Zoltan J. Acs and David B. Audretsch, "Entrepreneurship, Innovation and Technological Change," *Foundations and Trends in Entrepreneurship* 1, no. 4, June 2010, http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1629271. Young firms account for a smaller number of patents, but they are significantly more likely to file a radical patent than older firms. See Dan Andrews, Chiara Criscuolo, and Carlo Menon, "Do Resources Flow to Patenting Firms? Cross-Country Evidence from Firm Level Data," OECD Economics Department Working Paper no. 1127, 2014, http://www.law.northwestern.edu/research-faculty/searlecenter/events/innovation/documents/AndrewsCriscuoloMenon_SEARLE_jun14.pdf.
2. *OECD Science, Technology and Industry Outlook 2014* (Paris: Organization for Economic Cooperation and Development, 2014), p. 58, http://www.oecd.org/sti/oecd-science-technology-and-industry-outlook-19991428.htm.
3. Internationally comparable data on basic research is poor. Governments often do not distinguish between basic and applied research in national statistics. But according to data collected at the OECD, France is the only G7 country to apportion more money to basic research as a percentage of its GDP (0.59 percent) than the United States (0.55 percent). See figure 6, "Basic research expenditures as a percentage of GDP," Main Science and Technology Indicators, no. 1, OECD, 2012, http://www.oecd-ilibrary.org/science-and-technology/main-science-and-technology-indicators-volume-2012-issue-1/basic-research-expenditure-as-a-percentage-of-gdp_msti-v2012-1-table6-en.
4. "Global Top 100 Companies by Market Capitalisation, March 31, 2015 Update," PricewaterhouseCoopers, http://www.pwc.com/gx/en/audit-services/capital-market/publications/assets/document/pwc-global-top-100-march-update.pdf.
5. Science and Engineering Indicators 2014, figure O-1, "KTI share of GDP, by selected country/economy: 1999, 2005, and 2012," National Science Foundation, http://www.nsf.gov/statistics/seind14/index.cfm/etc/figures.htm.
6. Nicholas Bloom et al., "Management Practices Across Firms and Countries," Harvard Business School Working Paper no. 12-052, December 2011, http://www.hbs.edu/faculty/Publication%20Files/12-052.pdf; Nicholas Bloom, Raffaella Sadun, and John Van Reenen, "Americans Do IT Better: US Multinationals and the Productivity Miracle," *American Economic Review* 102, no. 1, 2012, http://web.stanford.edu/~nbloom/ADIB.pdf.
7. Calculated by PricewaterhouseCoopers, April 2015, based on data from the report "Global Top 100 Companies by Market Capitalisation." This does not include state-owned enterprises (SOEs). Several of the world's largest and most profitable companies are oil and gas SOEs like Saudi Arabia's Saudi Aramco or Mexico's Pemex.
8. Tom Gara, "Boosting R&D Spending: U.S. Companies Lead, But Volkswagen Is King," *Wall Street Journal,* June 11, 2014, http://blogs.wsj.com/corporate-intelligence/2014/06/11/boosting-rd-spending-u-s-companies-lead-but-volkswagen-is-king.

9. "Doing Business 2015: Going Beyond Efficiency," World Bank Group, 2014, http://www.doingbusiness.org/~/media/GIAWB/Doing%20Business/Documents/Annual-Reports/English/DB15-Chapters/DB15-Report-Overview.pdf.
10. Dan Andrews and Chiara Criscuolo, "Knowledge Based Capital, Innovation and Resource Allocation," OECD Economics Department Working Papers no. 1046, May 2013, p. 23, http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ECO/WKP%282013%2938&docLanguage=En.
11. For entrepreneurship rates, see Chiara Criscuolo, Peter N. Gal, and Carlo Menon, "The Dynamics of Employment Growth: New Evidence from 18 Countries," OECD Science, Technology and Industry Policy Papers no. 14, 2014, http://www.oecd-ilibrary.org/science-and-technology/the-dynamics-of-employment-growth_5jz417hj6hg6-en. For firm pace of growth and death, see Albert Bravo Biosca, "Growth Dynamics: Exploring Business Growth and Contraction in Europe and the US," NESTA Research Report, November 2010, http://www.nesta.org.uk/sites/default/files/growth_dynamics.pdf.
12. Dan Andrews and Federico Cingano, "Public Policy and Resource Allocation: Evidence from Firms in OECD Countries," *Economic Policy* 29, no. 78, April 2014, http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2443991.
13. Josh Lerner, *Boulevard of Broken Dreams: Why Public Efforts to Boost Entrepreneurship and Venture Capital Have Failed—and What to Do About It* (Princeton, NJ: Princeton University Press, 2009).
14. Edmund S. Phelps, "Entrepreneurial Culture," *Wall Street Journal*, February 12, 2007, http://www.wsj.com/articles/SB117124449952605357; Amar Bhidé, *The Venturesome Economy: How Innovation Sustains Prosperity in a More Connected World* (Princeton, NJ: Princeton University Press, 2008).
15. "Global Entrepreneurship Monitor 2014 Global Report," Global Entrepreneurship Research Association, 2014, http://www.gemconsortium.org/report.
16. Richard M. Locke and Rachel L. Wellhausen, eds, *Production in the Innovation Economy* (Cambridge, MA: MIT Press, 2014).
17. Bronwyn H. Hall, "The Stock Market's Valuation of R&D Investment during the 1980's," *American Economic Review: Papers and Proceedings* 83, no. 2, May 1993, https://ideas.repec.org/a/aea/aecrev/v83y1993i2p259-64.html.
18. Ashish Arora, Sharon Belenzon, and Andrea Patacconi, "Killing the Golden Goose? The Decline of Science in Corporate R&D," NBER Working Paper no. 20902, January 2015, http://www.nber.org/papers/w20902.pdf.
19. Ibid.
20. Dennis Patrick Leyden and Albert N. Link, *Public Sector Entrepreneurship: U.S. Technology and Innovation Policy* (New York: Oxford University Press, 2015); William J. Baumol, Robert Litan, and Carl Schramm, "Capitalism: Growth Miracle Maker, Growth Saboteur," in Zoltan Acs, David Audretsch, and Robert Strom, eds., *Entrepreneurship, Growth, and Public Policy* (New York: Cambridge University Press, 2009), p. 28.
21. Science and Engineering Indicators 2010, "Exports of high-technology manufactured goods, by country/economy: 1995–2008," National Science Foundation, http://www.nsf.gov/statistics/digest10/globalization.cfm#5.
22. Arora, Belenzon, and Patacconi, "Killing the Golden Goose?"
23. Science and Engineering Indicators 2012, figure 5-28, "Share of U.S., EU, and China S&E articles that are in the world's top 1% of cited articles: 2000–10," National Science Foundation, http://www.nsf.gov/statistics/seind12/c5/c5s4.htm.
24. CWTS Leiden Ranking 2015, http://www.leidenranking.com.

25. OECD Science, Technology and Industry Outlook 2014, figure 6.6, "Licensing income from public research, 2004–11," p. 212, http://www.oecd-ilibrary.org/docserver/download/9214011e.pdf?expires=1444401886&id=id&accname=ocid195235&checksum=F83C207AEFDFD03D205CD32F602FFF92.
26. Many countries are adopting legislation similar to the U.S. Bayh-Dole Act, which gave universities patenting rights to research funded by public money.
27. Philippe Aghion et al., "The Governance and Performance of Research Universities: Evidence from Europe and the U.S.," NBER Working Paper no. 14851, April 2009, http://www.nber.org/papers/w14851.pdf.
28. Richard F. Celeste, Ann Girswold, and Miron L. Straf, eds., *Furthering America's Research Enterprise* (Washington, DC: National Academies Press, 2014).
29. Pierre Azoulay, Joshua S. Gradd Zivin, and Gustavo Manso, "Incentives and Creativity: Evidence from the Academic Life Sciences," NBER Working Paper no. 15466, October 2009, http://www.nber.org/papers/w15466.pdf.
30. The NIH is trying to combat this problem through programs like the Pathway to Independence Award for younger researchers.
31. OECD Education at a Glance 2014, table B1.4, "Annual expenditure per student by educational institutions for all services, relative to GDP per capita (2011)," p. 218, http://www.oecd-ilibrary.org/docserver/download/9614011e.pdf?expires=1444402255 &id=id&accname=guest&checksum=53ED9BB503A2BE6C85D487CD1625F46E.
32. Science and Engineering Indicators 2014, table 4-2, "Annual Rates of Growth in U.S. R&D Expenditures, total and by performing sectors: 1991–2011," National Science Foundation, http://www.nsf.gov/statistics/seind14/index.cfm/chapter-4/tt04-02.htm.
33. Claudia Goldin and Lawrence F. Katz, *The Race Between Education and Technology* (Cambridge, MA: Harvard University Press, 2008), pp. 11–43.
34. Science and Engineering Indicators 2014, "Figure O-9: Researchers as a share of total employment in selected countries/regions: 1995–2011," National Science Foundation, http://www.nsf.gov/statistics/seind14/index.cfm/etc/figures.htm.
35. Jyoti Madhusoodanan, "2014 Life Sciences Salary Survey," *Scientist*, November 1, 2014, http://www.the-scientist.com/?articles.view/articleNo/41316/title/2014-Life-Sciences-Salary-Survey; "Remuneration of Researchers in the Public and Private Sectors," European Commission, 2007, http://ec.europa.eu/euraxess/pdf/research_policies/final_report.pdf.
36. OECD Science, Technology and Industry Scoreboard 2013, "Impact of Scientific Authors, by Category of Mobility, 1996–2011," p. 133, http://www.oecd-ilibrary.org/science-and-technology/oecd-science-technology-and-industry-scoreboard-2013/impact-of-scientific-authors-by-category-of-mobility-1996-2011_sti_scoreboard-2013-graph120-en.
37. Michael G. Finn, "Stay Rates of Foreign Doctorate Recipients from U.S. Universities, 2011," National Center for Science and Engineering Statistics of the National Science Foundation, January 2014, http://orise.orau.gov/files/sep/stay-rates-foreign-doctorate-recipients-2011.pdf.
38. Paula E. Stephan and Sharon G. Levin, "Exceptional Contributions to U.S. Science by the Foreign-born and Foreign-educated," *Population Research and Policy Review* 20, 2001, pp. 59–79, http://www.umsl.edu/~levins/Files/Exceptional%20contributions%20to% 20US%20science%20by%20the%20foreign-born%20and%20foreign-educated.pdf.
39. OECD Science, Technology and Industry Scoreboard 2013, "Impact of Scientific Authors," http://www.oecd-ilibrary.org/science-and-technology/oecd-science-technology-and-industry-scoreboard-2013/impact-of-scientific-authors-by-category-of-mobility-1996-2011_sti_scoreboard-2013-graph120-en.

40. Cornelia Lawson et al., "International Careers of Researchers in Biomedical Sciences: A Comparison of the U.S. and the UK," Science Policy Research Unit Working Paper Series no. 2015-09, March 2015, http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2609014.
41. "Researchers on the Move: The Impact of Brain Circulation," OECD Directorate for Science, Technology and Industry, 2013, http://www.oecd.org/sti/researchers-on-the-move-the-impact-of-brain-circulation.pdf.
42. Paula Stephan, Giuseppe Scellato, and Chiara Franzoni, "International Competition for PhDs and Postdoctoral Scholars: What Does (and Does Not) Matter," *Innovation Policy and the Economy* 15, no. 1, August 2015, pp.73–113, http://www.nber.org/chapters/c13403.pdf; and Bogdan State et al., "Where Does the U.S. Stand in the International Competition for Talent? Evidence from LinkedIn Data," April 2, 2014, http://paa2014.princeton.edu/papers/141226.
43. For a good review of trends in student migration, see "Open Doors 2014: Report on International Educational Exchange," Institute of International Education, Washington, DC, November, 2014, http://www.iie.org/Research-and-Publications/Open-Doors.
44. Carol Hymowitz, "Foreign-Born CEOs Are Increasing in the U.S., Rarer Overseas," *Wall Street Journal,* May 25, 2004, http://www.wsj.com/articles/SB108543349255419931.
45. Stephen Martin and John T. Scott, "The Nature of Innovation Market Failure and the Design of Public Support for Private Innovation," *Research Policy* 29, 2000, pp. 437–47, http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.196.7452& rep=rep1&type=pdf.
46. Main Science and Technology Indicators 2013, no. 1, table 53, "Government intramural expenditure on R&D (GOVERD) as a percentage of GDP," http://www.oecd-ilibrary.org/docserver/download/9420130111e1t053.pdf?expires=1435333569&id=id&accname=ocid195235&checksum=9A58902C17CD390858D6F79AA4F16BE7. Of G7 countries, only Germany spends more public funds on R&D as a percentage of GDP and the United States is close behind.
47. For government support for business R&D, see OECD R&D Tax Incentive Indicators, "Direct funding of business R&D and tax incentives for R&D, 2012 and 2006," December 2014, OECD National Accounts and Main Science and Technology Indicators, http://www.oecd.org/sti/outlook/e-outlook/stipolicyprofiles/competencestoinnovate/financingbusinessrdandinnovation.htm; for basic research spending, see figure 6, "Basic research expenditures as a percentage of GDP," OECD's Main Science and Technology Indicators 2012.
48. Matt Hourihan, "The Federal Life Sciences Budget: Update and Outlook," presented at the San Antonio Life Sciences Institute Academy Innovation Forum, March 25, 2015.
49. There is little basis for R&D benchmarks in empirical research. At the firm level, an extra dollar spent on R&D does lead to an extra dollar's worth of productivity. See Bronwyn H. Hall, "Effectiveness of Research and Experimentation Tax Credits: Critical Literature Review and Research Design," Office of Technology Assessment, U.S. Congress, June 15, 1995, http://eml.berkeley.edu/~bhhall/papers/BHH95%20OTArtax.pdf; *Measuring the Impacts of Federal Investments in Research: A Workshop Summary* (Washington, DC: National Academies Press, 2011), http://www.nap.edu/catalog/13208/measuring-the-impacts-of-federal-investments-in-research-a-workshop. But at the macroeconomic or national level, economists know extremely little about optimal public R&D investment levels. It is especially hard with basic research, which can have diffuse effects and take decades to percolate through the economy. There is no federal office that coordinates and assesses the overall

performance of R&D expenditures. Fortunately, there has been a big push in the last few years with Science of Science Policy and STARMETRICS initiatives, which collect better data and think through the best way to measure impact. For background, see Bruce A. Weinberg et al., "Science Funding and Short-Term Economic Activity," *Science* 344, no. 6179, April 4, 2014, http://www.sciencemag.org/content/344/6179/41.summary; Julia Lane and Stefano Bertuzzi, "Measuring the Results of Science Investments," *Science* 331, no. 6018, February 11, 2011, http://www.sciencemag.org/content/331/6018/678.summary.

50. Fred Block and Matthew R. Keller, eds., *State of Innovation: The U.S. Government's Role in Technology Development* (Boulder, CO: Paradigm, 2011), pp. 154–72.
51. Bronwyn H. Hall, "Effectiveness of Research and Experimentation Tax Credits," 1995.
52. The bulk of empirical evidence points to ratios that are not far away from one. See, for example, Bronwyn Hall and John Van Reenan, "How Effective are Fiscal Incentives for R&D? A Review of the Evidence," NBER Working Paper no. 7098, April 1999, http://www.nber.org/papers/w7098.pdf.
53. Xulia Gonzalez, Jordi Jaumandreu, and Consuelo Pazo, "Barriers to Innovation and Subsidy Effectiveness," *Rand Journal of Economics* 36, no. 4, 2005, http://people.bu.edu/jordij/papers/glez,jaumandreu,pazo.pdf.
54. Bronwyn H. Hall and Alessandro Maffioli, "Evaluating the Impact of Technology Development Funds in Emerging Economies: Evidence from Latin-America," Inter-American Development Bank Working Paper no. OVE/WP-01/08, January 2008, http://idbdocs.iadb.org/WSDocs/getdocument.aspx?docnum=1404775.
55. Ben Westmore, "R&D, Patenting and Growth: The Role of Public Policy," OECD Economics Department Working Papers no. 1047, 2013, http://www.oecd-ilibrary.org/economics/r-d-patenting-and-growth_5k46h2rfb4f3-en.
56. Isabel Busom, "Tax Incentives or Subsidies for R&D?" UNU-MERIT Working Paper no. 2012-056, July 1, 2012, http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2330222.
57. Alberto Bravo-Biosca et al., "What Drives the Dynamics of Business Growth?" OECD Science, Technology and Industry Papers No. 1, 2013, http://www.oecd-ilibrary.org/science-and-technology/what-drives-the-dynamics-of-business-growth_5k486qtttq46-en; Andrews and Criscuolo, "Knowledge Based Capital, Innovation and Resource Allocation."
58. Dirk Czarnitzki and Bernd Ebersberger, "Do Direct R&D Subsidies Lead to the Monopolization of R&D in the Economy," ZEW Discussion Paper no. 10-078, Mannheim, 2010, http://ftp.zew.de/pub/zew-docs/dp/dp10078.pdf.
59. Isabel Busom, "Tax Incentives or Subsidies for R&D?"; Massimo G. Colombo et al., "R&D Subsidies and the Performance of High-Tech Start-Ups," *Economics Letters* 112, no. 1, 2011, pp. 97–99, http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1679064.
60. Others include the Small Business Technology Transfer program, Advanced Technology Program, and the Manufacturing Extension Partnership program. The 1980 Bayh-Dole Act shifted intellectual property rights to universities that use public research funding, which made it easier for universities to commercialize their research. The 1980 Stevenson-Wydler Technology Innovation Act allowed national laboratories to look for commercialization opportunities of publicly funded research.
61. Lewis M. Branscomb and Philip E. Auerswald, "Between Invention and Innovation: An Analysis of Funding for Early-Stage Technology Development," NIST GCR no. 02–841, National Institute of Standards and Technology, November 2002, http://belfercenter.hks.harvard.edu/files/betweeninnovation.pdf.
62. Block and Keller, *State of Innovation.*

63. Joshua Lerner, "The Government as Venture Capitalist: The Long-Run Impact of the SBIR Program," *Journal of Business* 72, no. 3, July 1999, http://www.jstor.org/stable/10.1086/209616; Sabrina T. Howell, "Financing Constraints as Barriers to Innovation: Evidence from R&D Grants to Energy Startups," Job Market Paper, January 7, 2015, http://economics.yale.edu/sites/default/files/howell_innovation_finance_jmp_jan7.pdf.
64. Sabrina Howell, "Financing Constraints."
65. Albert N. Link and John T. Scott, *Bending the Arc of Innovation: Public Support of R&D in Small, Entrepreneurial Firms* (New York: Palgrave Pivot, 2013), http://www.palgrave.com/page/detail/bending-the-arc-of-innovation-albert-n-link/?K=9781137371584.
66. Some new programs include the NIH's National Center for Advancing Translational Sciences, the NSF's I-Corps, and the Office of Innovation and Entrepreneurship's i6 Challenge.
67. For example, ARPA-E helps energy companies break into energy markets, which involves more product development than pure research. Also see "Federal Policies and Innovation," Congressional Budget Office, November 2014, https://www.cbo.gov/sites/default/files/113th-congress-2013-2014/reports/49487-Innovation.pdf .
68. For further discussion of innovation prizes, see Erik Brynjolfsson and Andrew McAfee, *The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies* (New York: W. W. Norton, 2014).
69. For more information, see http://www.challenge.gov/list.
70. Sridhar Kota, "Revitalizing American Manufacturing: Putting '&' Back in R&D," presentation at Nanocellulose Nanomaterials—A Path Toward Commercialization, Washington, DC, May 20, 2014, http://www.nano.gov/sites/default/files/nanocellulose-kota.pdf.
71. Charles W. Wessner and Alan Wm. Wolff, eds., *Rising to the Challenge: U.S. Innovation Policy for the Global Economy* (Washington, DC: National Academies Press, 2012), pp. 74–75.
72. Hourihan, "The Federal Life Sciences Budget."
73. "The Future of Solar Energy: An Interdisciplinary MIT Study," Energy Initiative at the Massachusetts Institute of Technology, May 2015, https://mitei.mit.edu/system/files/MIT%20Future%20of%20Solar%20Energy%20Study_compressed.pdf.
74. For U.S. dominance in patents, see International Energy Agency, "Energy Technology RD&D and Innovation," figure 5.6, "Clean energy patents filed by inventor's country of origin," http://www.iea.org/etp/tracking/figures/rdd_innovation.
75. Fraunhofer Institute for Solar Energy Systems, "Photovoltaics Report," presented in Freiburg, Germany, August 10, 2015, slide 11, https://www.ise.fraunhofer.de/de/downloads/pdf-files/aktuelles/photovoltaics-report-in-englischer-sprache.pdf.
76. "Renewables 2015 Global Status Report," Renewable Energy Policy Network for the 21st Century (REN21), 2015, pp. 8–10. http://www.ren21.net/status-of-renewables/global-status-report.
77. Ibid, p. 20.
78. NIH funding doubled in just four years, leading to a surge in graduate fellowship and lab construction. But after the increase flattened out, there was an uncomfortable adjustment for young scientists and construction projects.
79. The 2007 America COMPETES Act had pledged to double the budget over seven years for research accounts at the National Science Foundation, the Department of Energy's Office of Science, and the National Institutes of Standards and Technology.
80. Celeste, Girswald, and Straf, *Furthering America's Research Enterprise*.
81. OECD Science, Technology and Industry Scoreboard 2013, figure 4.3.1, "Government funding of health-related R&D, 2012," http://www.oecd-ilibrary.org/sites/sti_scoreboard-

2013-en/04/03/index.html?contentType=&itemId=%2Fcontent%2Fchapter%2Fsti_scoreboard-2013-31-en&mimeType=text%2Fhtml&containerItemId=%2Fcontent%2Fserial%2F20725345&access ItemIds=%2Fcontent%2Fbook%2Fst_scoreboard-2013-en.

82. Matthew Herper, "The Decline of Pharmaceutical Research, Measured in New Drugs and Dollars," *Forbes,* June 27, 2011, http://www.forbes.com/sites/matthewherper/2011/06/27/the-decline-of-pharmaceutical-researchmeasured-in-new-drugs-and-dollars.
83. See, for example, Michael A. Heller, "The Boundaries of Private Property," *Yale Law Journal* 108, no. 5, 1999, http://papers.ssrn.com/sol3/papers.cfm?abstract_id=146230; Simon Johnson, John McMillan, and Christopher Woodruff, "Property Rights and Finance," NBER Working Paper no. 8852, March 2002, http://www.nber.org/papers/w8852.
84. Michele Boldrin and David K. Levine, "The Case Against Patents," Federal Reserve Bank of St. Louis Working Paper no. 2012-035A, September 2012, https://research.stlouisfed.org/wp/2012/2012-035.pdf.
85. James Bessen and Michael J. Meurer, *Patent Failure: How Judges, Bureaucrats, and Lawyers Put Innovators at Risk* (Princeton, NJ: Princeton University Press, 2008).
86. "Intellectual Property: Assessing Factors That Affect Patent Infringement Litigation Could Help Improve Patent Quality," U.S. Government Accountability Office, August 2013, http://www.gao.gov/assets/660/657103.pdf.
87. James Bessen and Michael J. Meurer, "The Patent Litigation Explosion," *Loyola University Chicago Law Journal* 45, no. 2, 2013, http://lawecommons.luc.edu/cgi/viewcontent.cgi?article=1421&context=luclj.
88. Iain M. Cockburn and Megan J. MacGarvie, "Patents, Thickets and the Financing of Early-Stage Firms: Evidence from the Software Industry," *Journal of Economics & Management Strategy* 18, no. 3, 2009, http://onlinelibrary.wiley.com/doi/10.1111/j.1530-9134.2009.00228.x/full.
89. Data compiled by Patent Freedom, http://www.patentfreedom.com.
90. For reform ideas, see "Federal Policies and Innovation," CBO, pp. 36–40.
91. James Bessen and Michael J. Meurer, "The Private Costs of Patent Litigation," *Journal of Law, Economics and Policy* 9, no.1, 2012, http://jlep.net/home/wp-content/uploads/2013/02/JLEP-Issue-9.1.pdf.
92. See H.R. 3309 Innovation Act, sponsored by Rep. Bob Goodlatte (R-VA), https://www.congress.gov/bill/113th-congress/house-bill/3309.
93. Demetrios G. Papademetriou and Madeleine Sumption, "The Role of Immigration in Fostering Competitiveness in the United States," Migration Policy Institute, May 2011, p. 14, http://www.migrationpolicy.org/research/role-immigration-fostering-competitiveness-united-states.
94. Nonprofits like universities and public research labs, however, are exempt from the H-1B cap.
95. For share of permanent visas work-related, see International Migration Outlook 2014, figure 1.4, "Permanent immigration by category of entry or of status change into selected OECD countries, 2012," OECD, 2014, http://ekke.gr/ocd/wp-content/uploads/ 2014/12/SOPEMI-2014-E.pdf; for share of immigrants with a tertiary degree, see International Migration Outlook 2014, figure 2.2, "Share of the highly educated among the foreign- and native-born of working age (fifteen- to sixty-four-year-olds), 2013"; for index comparing restrictiveness of immigration systems for the high skilled, see Lucie Cerna, *Immigration Policy and the Global Competition for Talent* (London: Palgrave, 2015).

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