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A Toolkit of Policies to Promote Innovation

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The US economy has experienced a slowdown in productivity growth since the 1970s, which—except for an upward blip between 1996 and 2004—has been remarkably persistent. Other developed countries have also experienced this disappointing productivity trend. Moreover, slow productivity growth has been accompanied by disappointing real wage growth for most US workers, as well as rising wage inequality.

Innovation is the only way for the most developed countries to secure sustainable long-run productivity growth. For nations farther from the technological frontier, catch-up growth is a viable option, but this cannot be the case for leading-edge economies such as the United States, Japan, and the nations of Western Europe. For countries such as these, what are the most effective policies for stimulating technological innovation?

In this article, we take a practical approach to addressing this question. If a policymaker came to us with a fixed budget of financial and political capital to invest in innovation policy, what would we advise? We discuss a number of the main innovation policy levers and describe the available evidence on their effectiveness: tax policies to favor research and development, government research grants, policies aimed at increasing the supply of human capital focused on innovation, intellectual

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property policies, and pro-competitive policies. In the conclusion, we synthesize this evidence into a single-page "toolkit," in which we rank policies in terms of the quality and implications of the available evidence and the policies' overall impact from a social cost-benefit perspective. We also score policies in terms of their speed and likely distributional effects.

We do not claim that innovation policy is the *only* solution to America's productivity problem. Indeed, even within the United States, many firms are well behind the technological frontier, and helping these firms catch up—for example, by improving management practices—would likely have very high value. Nonetheless, we believe that sensible innovation policy design is a key part of the solution for revitalizing leading economies and will lead to large long-run increases in welfare. Before beginning our tour, we start with some background facts and then address an obvious question: why should a policymaker spend any resources at all on innovation?

Some Background Facts

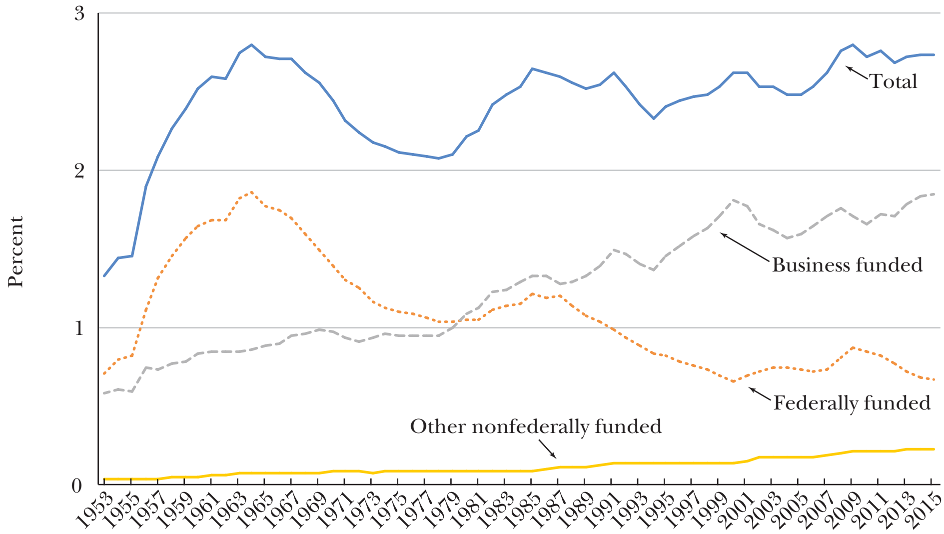
In 2015, spending on research and development (R&D) performed in the United States stood at just over $495 billion.[1] Figure 1 shows how this amount has evolved over time since 1953, in total as well as separately for R&D funded by businesses, the federal government, and other institutions (including state and local governments), as a share of GDP. R&D spending as a share of GDP grew from around 1.3 percent in 1953 to around 2.7 percent in 2015. Over time, there has been a relative decline in the share of R&D funded by the federal government, and in 2015, businesses spent more than twice as much as the federal government on R&D. Table 1 provides some points of international comparison for these statistics, tabulating R&D expenditures and R&D as a share of GDP in the United States, the nine other largest economies (as measured by GDP in 2015), and the OECD average. The United States spends more on R&D than these other countries, but R&D as a share of GDP in the United States is smaller than in Germany and Japan.

In recent years, around 13 percent of US research and development has been performed at colleges and universities. This R&D is also relatively unique in the sense that just under half of US R&D on basic research is undertaken at colleges and universities. From the perspective of these institutions, in recent years just over half of R&D expenditures at US colleges and universities have been federally funded. The vast bulk of that funding goes to the life sciences, with smaller amounts going to engineering, the physical sciences, and other fields.

Another set of metrics of innovative activity focus on the scientific workforce. The fraction of workers who are researchers grew through 2000 in the United States but has been stable between 0.7 and 0.9 percent since. The European Union has a similar fraction, while Japan is closer to 1 percent.

[1] Unless otherwise noted, all data and facts in this section—and later in the paper—are drawn from National Science Board (2018).

Figure 1
US Research and Development as a Share of GDP, by Source of Funds: 1953–2015



Source: This figure displays data from figure 4-3 of National Science Board (2018), chap. 4. The original data are drawn from the National Science Foundation, National Center for Science and Engineering Statistics, National Patterns of R&D Resources (annual series).
Notes: The figure shows how spending on R&D performed in the United States, presented as a share of GDP, has evolved over time from 1953 to 2015, in total and broken down by source of R&D funding.

One additional metric relevant to the size of the US scientific workforce is the number of temporary work visas issued in categories that cover high-skilled workers: J-1 (exchange visitors), H-1B, and L-1 (intracompany transferee) visas. Between 1991 and 2015, the primary increase in these categories was in J-1 visas, which increased from around 150,000 to over 330,000. The number of H-1B visas increased from around 52,000 in 1991 to nearly 175,000 in 2015. A cap of 65,000 H-1B visas was in place over that entire period, implying that the growth was driven by H-1Bs issued to employees of universities, nonprofit research facilities, and government research facilities, all of which are exempt from the annual H-1B quotas.

Why Should Governments Promote Innovation?

Governments often want to increase innovation in an attempt to encourage economic growth; indeed, countries that have higher levels of research and development spending are typically richer (see, for example, Jones 2015). However, standard economic theory suggests that, in the absence of market failures, it would be better for the government to leave investment decisions in the hands of private firms. There are many oft-cited government failures, such as the Concorde Anglo-French supersonic jet (for many other examples, see Lerner 2009). On

Table 1
International Comparison of Research and Development Expenditures in 2015

Country	*R&D expenditures (billions of US$)*	*R&D/GDP (%)*
United States	496.6	2.7
China	408.8	2.1
India	50.3	0.6
Japan	170.0	3.3
Germany	114.8	2.9
Russia	38.1	1.1
Brazil	38.4	1.2
France	60.8	2.2
United Kingdom	46.3	1.7
Indonesia	2.1	0.1
OECD (average)	34.7	2.4

Source: These data are drawn from table 4-5 of National Science Board (2018), chap. 4. The original data are drawn from the OECD, Main Science and Technology Indicators (2017/1); United Nations Educational, Scientific, and Cultural Organization Institute for Statistics Data Centre (http://data.uis.unesco.org/; accessed October 13, 2017).
Notes: This table displays data on gross domestic expenditures on R&D (reported in purchasing power parity adjusted billions of US dollars) and R&D as a share of GDP for the United States, the nine other countries with the largest GDP in 2015, and the OECD average (averaged over all 36 member countries as of 2015).

the other hand, there are also many examples of impressive inventions built on government-sponsored R&D, such as jet engines, radar, nuclear power, the Global Positioning System (GPS), and the internet (Janeway 2012; Mazzucato 2013).

Knowledge spillovers are the central market failure on which economists have focused when justifying government intervention in innovation. If one firm creates something truly innovative, this knowledge may spill over to other firms that either copy or learn from the original research—without having to pay the full research and development costs. Ideas are promiscuous; even with a well-designed intellectual property system, the benefits of new ideas are difficult to monetize in full. There is a long academic literature documenting the existence of these positive spillovers from innovations.

That said, economic theory also suggests that research and development expenditures in a market economy can be either too low or too high, depending on the net size of knowledge spillovers relative to what could be termed product market spillovers. The key idea behind product market spillovers is that private incentives can lead to business-stealing overinvestment in R&D because innovator firms may steal market share from other firms without necessarily generating any social benefit. A classic example is the case of pharmaceuticals, where one firm may spend billions of dollars to develop a drug that is only incrementally better than a drug produced by a rival firm—a “me too” drug. However, the small improvement in therapeutic value may allow the second firm to capture nearly the entire market. In cases where "me too" drugs are therapeutically indistinguishable from the products that they replace (and setting aside the possibility that such drugs may generate the benefit of price-cutting competition), this dynamic potentially generates a massive private benefit for shareholders of pharmaceutical firms, with little gain for patients.

Broadly stated, three methods have been used to estimate spillovers: case studies, a production function approach, and research based on patent counts.

Perhaps the most famous example of the case study approach is Griliches (1958), which estimates the social rate of return realized by public and private investments in hybrid corn research. Griliches estimates an annual return of 700 percent, as of 1955, on the average dollar invested in hybrid corn research. Seed or corn producers appropriated almost none of these returns; they were instead passed to consumers in the form of lower prices and higher output. While this study is widely cited, Griliches himself discusses the challenges inherent in calculating the rate of return on something akin to a successful "oil well." Although we typically observe an estimate that captures the cost of drilling and developing a successful well, we would ideally prefer to generate an estimate that includes the cost of all of the "dry holes" drilled before oil was struck. For more specific examples of diffusion, see the data compiled by Comin and Hobijn (2010).

The production function approach abandons the details of specific technologies and instead relates productivity growth (or other measures of innovative output) to lagged measures of investment in research and development. The key challenge here is that R&D is determined by many factors that also independently affect productivity. Recent papers applying this approach have used policy experiments that influence R&D investments to identify the arrow of causality (for example, Bloom, Schankerman, and Van Reenen 2013).

The key idea in using patent citations to measure spillovers is that each patent cites other patents, all of which form the basis of "prior art"—existing innovations that enabled that particular patent. Trajtenberg (1990) and Jaffe, Trajtenberg, and Henderson (1993) pioneered this approach. Although there is some evidence that citations can be strategic (and that some citations are added by patent examiners during the course of the patent examination process), the existence of patent citations provides a measurable indication of knowledge spillovers (see, for example, Griffith, Lee, and Van Reenen 2011). As already noted, a challenge with the production function approach is finding ways of identifying the relevant channels of influence so that "one can detect the path of spillovers in the sands of the data" (Griliches 1992). Herein lies an advantage of using patent citations, which provide a direct way of inferring *which* firms receive spillover benefits.

More generally, the trick in the search for spillovers has been to focus on defining a dimension (or dimensions) over which spillovers are mediated. Firms less distant from each other in this dimension will be more affected by the research and development efforts of their peers. Examples include technological distance as revealed from past patenting classes (Jaffe 1986), geographical distance between corporate R&D labs, and product market distance (the industries in which firms operate). As a whole, this literature on spillovers has consistently estimated that social returns to R&D are much higher than private returns, which provides a justification for government-supported innovation policy. In the United States, for example, recent estimates in Lucking, Bloom, and Van Reenen (2018) used three decades of firm-level data and a production function–based approach to document evidence of substantial positive net knowledge spillovers. The authors estimate that social returns are about 60 percent, compared with private returns of around 15 percent, suggesting the case for a substantial increase in public research subsidies.

Given this evidence on knowledge spillovers, one obvious solution is to provide strong intellectual property rights such as patents to inventors as a means of increasing the private return to inventing. A patent is a temporary right to exclude others from selling the protected invention. Patents entail some efficiency loss because they usually enable sellers to charge a higher price markup over production costs. However, this downside could be outweighed by the gains in dynamic efficiency that arise from patents providing stronger incentives to do more research and development because potential innovators expect to be able to appropriate more of the benefits for their efforts. In practice, as we will discuss in more detail below, the patent system is highly imperfect. For one thing, other firms can frequently invent around a patent—after all, the empirical evidence on knowledge spillovers summarized above is drawn from data on the United States, which already has a strong system of intellectual property rights by international standards.

In addition to spillovers, there are other potential justifications for research and development subsidies, related to failures in other markets. For example, financial constraints may limit the amount of innovation that firms can carry out. Because innovation is intangible, it may be hard for firms to raise funding when they have no collateral to pledge to banks in return for debt funding. This insight suggests that equity might be a better source of funding for innovation, but equity faces a different challenge: an asymmetry of information. Before innovations are patented or demonstrated in the market, the requisite secrecy about technology makes fundraising difficult. A pitch of "trust me, I have a great idea, so please fund me" is rarely effective, whereas a pitch of "let me describe my not-yet-patented idea in detail" opens up the possibility of potential investors stealing an idea from the entrepreneur.

Evidence suggests that financial constraints often do hold back innovation (for a survey, see Hall and Lerner 2010). However, the presence of financial constraints around research and development funding is not necessarily a reason for government subsidies: governments often have worse information about project quality than either firms or investors, so designing appropriate policy interventions is difficult. Effective policies to address financial constraints involve not just financial support for firms but also a mechanism to identify and select higher-quality investments acurately, which is typically difficult to do.

We now turn to discussing a number of the main innovation policy levers: tax policies to favor research and development, government research grants, policies aimed at increasing the supply of human capital focused on innovation, intellectual property policies, and pro-competitive policies.

Tax Incentives for Research and Development

The tax code automatically treats research and development expenditures by firms more generously than tangible capital investment. In particular, because most R&D expenses are current costs—like scientists' wages and lab materials—they can be written off in the year in which they occur. By contrast, investments in long-lasting assets such as plant, equipment, and buildings must be written off over a multiyear period; this allows a firm to reduce its tax liabilities only at some point in the future.

But over and above this tax structure advantage, many countries provide additional fiscal incentives for research and development, such as allowing an additional deduction to be made against tax liabilities. For example, if firms treat 100 percent of their R&D as a current expense, and the corporate income tax rate is 20 percent, then every $1 of R&D expenditure reduces corporate taxes by $0.20. However, if a government allows a 150 percent rate of superdeduction, again assuming a corporate tax rate of 20 percent, then $1 of R&D spending would reduce corporate taxes by $0.30. President Reagan introduced the first Research and Experimentation Tax Credit in the United States in 1981. This policy currently costs the US federal government about $11 billion a year in foregone tax revenue (National Science Board 2018), with an additional $2 billion a year of lost tax revenue from state-level R&D tax credits (which started in Minnesota in 1982).

The OECD (2018) reports that 33 of the 42 countries it examined provide some material level of tax generosity toward research and development. The US federal R&D tax credit is in the bottom one-third of OECD nations in terms of generosity, reducing the cost of US R&D spending by about 5 percent. This is mainly because the US tax credit is based on the incremental *increase* in a firm's R&D over a historically defined base level, rather than being a subsidy based on the total amount of R&D spending. In countries with the most generous provisions, such as France, Portugal, and Chile, the corresponding tax incentives reduce the cost of R&D by more than 30 percent.

Do research and development tax credits actually work to raise R&D spending? The answer seems to be "yes." One narrow approach to the question asks whether the quantity of R&D increases when its tax price falls. This question is of interest in part because most people (and many expert surveys) suggest that R&D is driven by advances in basic science and perhaps by market demand, rather than by tax incentives. There are now a large number of studies that examine changes in the rules determining the generosity of tax incentives by using a variety of data and methodologies (for a survey, see Becker 2015). Many early studies used cross-country panel data (Bloom, Griffith, and Van Reenen 2002) or US cross-state data (Wilson 2009) and related changes in R&D to changes in tax rules. Some more recent studies have used firm-level data and exploited differential effects of tax rules across firms before a surprise policy change. For example, firms below a size threshold may receive a more generous tax treatment, so one can compare firms just below and just above the threshold after (and before) the policy change by using a regression discontinuity design (Dechezleprêtre et al. 2016). Taking the macro and micro studies together, a reasonable overall conclusion would be that a 10 percent fall in the tax price of R&D results in at least a 10 percent increase in R&D in the long run; that is, the absolute elasticity of R&D capital with respect to its tax-adjusted user cost is unity or greater.

One concern for both research and policy is that firms may relabel existing expenditures as "research and development" to take advantage of the more generous tax breaks. Chen et al. (2019), for example, found substantial relabeling following a change in Chinese corporate tax rules. A direct way to assess the success of the R&D tax credit is to look at other outcomes such as patenting, productivity, or jobs. Encouragingly, these more direct measures also seem to increase (with a lag) following tax changes (for US evidence, see Lucking 2019 and Akcigit et al. 2018; for the United Kingdom, see Dechezleprêtre et al. 2016; for China, see Chen et al. 2019; and for Norway, see Bøler, Moxnes, and Ulltveit-Moe 2015).

Another concern is that research and development tax credits may not raise aggregate R&D but rather may simply cause a relocation toward geographical areas with more generous fiscal incentives and away from geographical areas with less generous incentives. US policymakers may not care so much if tax credits shift activity from, say, Europe to the United States, but we expect them to care if state-specific credits simply shift around activity from one state to another. There are a wide variety of local policies explicitly trying to relocate innovative activity across places within the United States by offering increasingly generous subsidies. For example, Amazon's second headquarters generated fierce competition, with some cities offering subsidies up to $5 billion. This is likely to cause some distortions, as the areas that bid the most are not always the places where the research will be most socially valuable.

There is some evidence of relocation in response to tax incentives. In the context of individual inventor mobility and personal tax rates, Moretti and Wilson (2017) find cross-state relocation within the United States, and Akcigit, Baslandze, and Stantcheva (2016) document a similar relocation pattern in an international dimension. Wilson (2009) and Bloom and Griffith (2001) also document some evidence of relocation in response to research and development tax credits. However, relocation alone does not appear to account for all of the observed changes in innovation-related outcomes. Akcigit et al. (2018) test explicitly for relocation and estimate effects of tax incentive changes on nonrelocating incumbents. Overall, the conclusion from this literature is that despite some relocation across place, the aggregate effect of R&D tax credits at the national level both on the volume of R&D and on productivity is substantial.

Patent Boxes

"Patent boxes," first introduced by Ireland in the 1970s, are special tax regimes that apply a lower tax rate to revenues linked to patents relative to other commercial revenues. By the end of 2015, patent boxes (or similarly structured tax incentives related to intellectual property) were used in 16 OECD countries (Guenther 2017). Although patent box schemes purport to be a way of incentivizing research and development, in practice they induce tax competition by encouraging firms to shift their intellectual property royalties into different tax jurisdictions. Patent boxes provide a system through which firms can manipulate stated revenues from patents to minimize their global tax burden (Griffith, Miller, and O'Connell 2014) because firms—particularly multinational firms—have considerable leeway in deciding where they will book their taxable income from intellectual property. Although it may be attractive for governments to use patent box policies to collect footloose tax revenues (Choi 2019), such policies do not have much effect on the real location or the quantity of either R&D or innovation. Gaessler, Hall, and Harhoff (2018) find a small effect of the introduction of patent boxes in several EU countries on transfers of the ownership of patents, but zero effect on real invention.

Our take is that patent boxes are an example of a harmful form of tax competition that distorts the tax system under the guise of being a pro-innovation policy. In contrast to well-designed research and development tax credits—for which it is hard to manipulate the stated location of research labs—patent boxes should be discouraged.

Government Research Grants

A disadvantage of tax-based support for research and development is that tax policies are difficult to target at the R&D that creates the most knowledge spillovers and avoids business-stealing. In contrast, government-directed grants can more naturally do this type of targeting by focusing on, for example, basic R&D, such as that performed in universities, rather than more applied R&D that occurs in an industry setting. A variety of government programs seek to encourage innovation by providing grant funding, either to academic researchers—such as through the US National Institutes of Health (NIH)—or to private firms, such as through the Small Business Innovation Research (SBIR) program. How effective are these programs?

Evaluating the effectiveness of grant funding for research and development is challenging. Public research grants usually (and understandably) attempt to target the most promising researchers, the most promising projects, or the most socially important problems. As a result, it is difficult to construct a counterfactual for what would otherwise have happened to the researchers, firms, or projects that receive public R&D funds. If $1 of public R&D simply crowds out $1 of private R&D that would otherwise have been invested in the same project, then public R&D could have no real effect on overall R&D allocations (much less on productivity or growth). However, it is also possible that public R&D grants add to private R&D spending, or even that public R&D "crowds in" and attracts additional private R&D spending.

Jacob and Lefgren (2011) use administrative data on US grant applications to the National Institutes of Health and effectively compare academic applicants who just barely received and just missed receiving large NIH grants. They document that these grants produce positive but small effects on research output, leading to about one additional publication over five years (an increase of 7 percent). One explanation for this modest effect is that marginal unsuccessful NIH grant applicants often obtain other sources of funding to continue their research. Consistent with that story, productivity effects are larger among researchers who are likely to be more reliant on NIH funding (for whom alternative funding sources may be less likely to be available).

Looking beyond academic output, public research and development grants may affect private firms in several ways. First, public R&D grants to academics can generate spillovers to private firms. Azoulay, Graff Zivin, et al. (2019) exploit quasi-experimental variation in funding from the National Institutes of Health across research areas to show that a $10 million increase in NIH funding to academics leads to 2.7 additional patents filed by private firms. Second, private firms themselves sometimes conduct publicly funded R&D. Moretti et al. (2019) use changes in military R&D spending, which is frequently driven by exogenous political changes, to look at the effect of public subsidies for military R&D. They document that a 10 percent increase in publicly funded R&D to private firms results in a 3 percent increase in private R&D, suggesting that public R&D crowds in private R&D (and also, they document, raises productivity growth). Third, private firms can directly receive public subsidies. Howell (2017) examines outcomes for Small Business Innovation Research grant applicants, comparing marginal winners and losers. She estimates that early-stage SBIR grants roughly double the probability that a firm receives subsequent venture capital funding, and that receipt of an SBIR grant has positive impacts on firm revenue and patenting.

Two other important aspects of public grant support for research and development are worth mentioning. First, a substantial share of public R&D subsidies goes to universities, which makes sense from a policy perspective, as spillovers from basic academic research are likely to be much larger than those from near-market applied research. There certainly appears to be a correlation between areas with strong science-based universities and private sector innovation (for example, Silicon Valley in California, Route 128 in Massachusetts, and the Research Triangle in North Carolina). Jaffe (1989) pioneered research in this area by documenting important effects of academic R&D on corporate patenting, a finding corroborated by Belenzon and Schankerman (2013) and Hausman (2018).[2]

Governments can also fund their own research and development labs—for example, SLAC National Accelerator Laboratory at Stanford University. These labs can generate more research activity and employment in the technological and geographical area in which the lab specializes. For example, the United Kingdom's Diamond Light Source synchrotron appeared to do this (Helmers and Overman 2016), but in that case the increase seems to have occurred mainly through relocation of research activity within the United Kingdom rather than an overall increase in aggregate research.

[2]Jaffe and Lerner (2001) analyze national labs, which are often managed by universities, and also document evidence of spillovers. Valero and Van Reenen (2019) offer a generally positive survey on the impact of universities on productivity overall and on innovation specifically. Hausman (2018) and Andrews (2019) also find positive effects of universities on US innovation.

There has also been controversy over how to design complementary policies that enable the resulting discoveries—when made at universities—to be translated into technologies that benefit consumers. The 1980 Bayh–Dole Act in the United States made some key changes in the ownership of inventions developed with public research and development support. In part because of Bayh–Dole, universities have an ownership share in the intellectual property developed by those working at their institutions, and many universities set up "technology transfer offices" to provide additional support for the commercialization of research. Lach and Schankerman (2008) provide evidence consistent with greater ownership of innovations by scientists being associated with more innovation. In addition, evidence from Norway presented in Hvide and Jones (2018) suggests that when university researchers enjoy the full rights to their innovations, they are more likely to patent inventions as well as launch start-ups. That is, ideas that might have remained in the "ivory tower" appear more likely to be turned into real products because of changes in the financial returns to academic researchers.

Human Capital Supply

So far, we have focused attention on policies that increase the demand for research and development by reducing its cost via the tax system or via direct grant funding. However, consider an example in which we assume that scientists carry out all R&D and that the total number of scientists is fixed. If the government increases demand for R&D, the result will simply be higher wages for scientists, with zero effect on the quantity of R&D or innovation. Of course, this example is extreme. There is likely to be some ability to substitute away from other factors into R&D. Similarly, there is likely some elasticity of scientist supply in the long run as wages rise and, through immigration from other countries, in the short run.[3] However, the underlying message is that increasing the quantity of innovative activity requires increasing the supply of workers with the human capital needed to carry out research, as emphasized by Romer (2001). This rise in supply increases the volume of innovation directly as well as boosting R&D indirectly by reducing the equilibrium price of R&D workers. In addition, since these workers are highly paid, increasing the supply of scientific human capital will also tend to decrease wage inequality.

Many policy tools are available that can increase the supply of scientific human capital. In terms of frontier innovation, perhaps the most direct policy is to increase the quantity and quality of inventors. There have been many attempts to increase the number of individuals with training in science, technology, engineering, and mathematics (commonly known as STEM). Evaluating the success of such policies

[3] This insight also suggests that general equilibrium effects of a research and development tax credit may partially undermine its effects on innovation. These effects are hard to detect with micro data. Some macro studies do show partial crowding out (Goolsbee 1998), whereas others do not (Bloom, Griffith, and Van Reenen 2002). Atkeson and Burstein (forthcoming) put these together in a macro model that shows large long-run welfare effects of innovation policies.

is difficult given that these policies tend to be economy-wide, with effects that will play out only in the long run.

One strand of this literature has focused on the location, expansion, and regulation of universities as key suppliers of workers in science, technology, engineering, and mathematics. For example, Toivanen and Väänänen (2016) document that individuals growing up around a technical university (such institutions rapidly expanded in the 1960s and 1970s in Finland) were more likely to become engineers and inventors. Of course, such policies could increase the supply of workers with qualifications in STEM fields, but research and innovation by university faculty could also directly affect local area outcomes.

Bianchi and Giorcelli (2018) present results from a more direct test of the former explanation by exploiting a change in the enrollment requirements for Italian majors in science, technology, engineering, and mathematics, which expanded the number of graduates. They document that this exogenous increase in STEM majors led to more innovation in general, with effects concentrated in particular in chemistry, medicine, and information technology. They also document a general "leakage" problem that may accompany efforts to simply increase the STEM pipeline: many STEM-trained graduates may choose to work in sectors that are not especially focused on research and development or innovation, such as finance.

Migration offers an alternative lens into the effects of human capital on innovation. Historically, the United States has had a relatively open immigration policy that helped to make the nation a magnet for talent. Immigrants make up 18 percent of the US labor force aged 25 and over but constitute 26 percent of the science, technology, engineering, and mathematics workforce. Immigrants also own 28 percent of higher-quality patents (as measured by those filed in patent offices of at least two countries) and hold 31 percent of all PhDs (Shambaugh, Nunn, and Portman 2017). A considerable body of research supports the idea that US immigrants, especially high-skilled immigrants, have boosted innovation. For example, Kerr and Lincoln (2010) exploit policy changes affecting the number of H1-B visas and argue that the positive effects come solely through the new migrants' own innovation.[4] Using state panel data from 1940 to 2000, Hunt and Gauthier-Loiselle (2010) document that a 1 percentage point increase in immigrant college graduates' population share increases patents per capita by 9 to 18 percent, and they argue for a spillover effect to the rest of the population. Bernstein et al. (2018) use the death of an inventor as an exogenous shock to team productivity and argue for large spillover effects of immigrants on native innovation.

The US federal government's introduction of immigration quotas with varying degrees of strictness in the early 1920s—for example, Southern Europeans, such as Italians, were more strongly affected than Northern Europeans, such as Swedes—has

[4] Using H1-B visa lotteries, Doran, Gelber, and Isen (2014) estimate smaller effects than Kerr and Lincoln (2010). By contrast, Borjas and Doran (2012) document negative effects on publications by Americans in mathematics journals following the fall of the Soviet Union, although they do not attempt to estimate aggregate effects; their findings may reflect a feature specific to academic publishing, where there are (short-run) constraints on the sizes of academic journals and departments. Moser, Voena, and Waldinger (2014) estimate that most of the effect of immigration on innovation came from new entry.

been used to document how exogenous reductions in immigration damaged innovation. Moser and San (2019) use rich biographical data to show that these quotas discouraged Eastern and Southern European scientists from coming to the United States and that this reduced aggregate invention. Doran and Yoon (2018) also find negative effects of these quotas. Moser, Voena, and Waldinger (2014) show that American innovation in chemistry was boosted by the arrival of Jewish scientists who were expelled by the German Nazi regime in the 1930s.

Overall, most of the available evidence suggests that increasing the supply of human capital through expanded university programs and/or relaxed immigration rules is likely to be an effective innovation policy.

A final way to increase the quantity supplied of research and development is to reduce the barriers to talented people becoming inventors in the first place. Children born in low-income families, women, and minorities are much less likely to become successful inventors. Bell et al. (2019), for example, document that US children born into the top 1 percent of the parental income distribution are ten times more likely to grow up to be inventors than are those born in the bottom half of the distribution. The authors show that relatively little of this difference is related to innate ability. A more important cause of the lower invention rate for disadvantaged groups appears to be differential exposure rates to inventors in childhood. This implies that improved neighborhoods, better school quality, and greater exposure to inventor role models and mentoring could arguably raise long-run innovation.

Intellectual Property

The phrase "intellectual property" is often used to refer to a suite of policies including patents, copyrights, and other instruments such as trademarks. Although these policies have some broad similarities, they differ in meaningful ways. For example, a patent grants—in exchange for disclosure of an invention—a limited-term property right to an inventor, during which time the inventor has the right to exclude others from making, using, or selling their invention. A copyright, in contrast, provides a limited term of protection to original literary, dramatic, musical, and artistic works, during which time the author has the right to determine whether, and under what conditions, others can use their work. The legal rules governing patents and copyrights are distinct, and the practical details of their implementation are quite different; for example, copyright exists from the moment a work is created (although as a practical matter it can be difficult to bring a lawsuit for infringement if you do not register the copyright), whereas an inventor must actively choose to file a patent application, and patent applications are reviewed by patent examiners. Nonetheless, patents and copyrights have many similarities from an economic perspective, and economists—to the chagrin of some lawyers—often lump the two types of policies together.

Boldrin and Levine (2013, in this journal) have argued that the patent system should be completely abolished, based on the view that there is no evidence that patents serve to increase innovation and productivity. Although the patent system has many problems, outright abolition is—in our view—an excessive response. However, many different elements of patents could be strengthened or loosened. We focus here on two specific areas currently under active policy debate.

First, what types of technologies should be patent eligible? The US Patent and Trademark Office is tasked with awarding patent rights to inventions that are novel, nonobvious, and useful and whose application satisfies the public disclosure requirement. The US Supreme Court has long interpreted Section 101 of Title 35 of the US Code as implying that abstract ideas, natural phenomena, and laws of nature are patent-ineligible. Several recent Court rulings have relied on Section 101 to argue that various types of inventions should no longer be patent eligible: business methods (*Bilski v. Kappos*, 561 US 593 [2010]), medical diagnostic tests (*Mayo Collaborative Services v. Prometheus Laboratories, Inc.*, 566 US 66 [2012]), human genes (*Association for Molecular Pathology v. Myriad Genetics, Inc.*, 569 US 576 [2013]), and software (*Alice Corp. v. CLS Bank International*, 573 US 208 [2014]). A reasonable interpretation of these legal rulings is that the Court is "carving out" certain areas where the perceived social costs of patents outweigh the perceived social benefits. For example, in the 2012 *Mayo v. Prometheus* case, the Court argued that the patenting of abstract ideas such as medical diagnostic tests might impede, more than encourage, innovation. This question is fundamentally empirical, but the available empirical evidence provides only rather inconclusive hints at the answer to that question, rather than a systematic basis for policy guidance (Williams 2013, 2017; Sampat and Williams 2019).

Second, many current debates about patent reform center on "patent trolls," a pejorative term that refers to certain "nonpracticing entities," or patent owners who do not manufacture or use a patented invention but instead buy patents and then seek to enforce patent rights against accused infringers. The key question here is whether litigation by so-called patent trolls is frivolous. On one hand, Haber and Levine (2014) argue that the recent uptick in patent litigation generally associated with the rise of patent trolls may in fact not be evidence of a problem. They argue that—historically—spikes in litigation have coincided with the introduction of disruptive technologies (such as the telegraph and the automobile) and that there is no evidence that the current patent system either harms product quality or increases prices. On the other hand, Cohen, Gurun, and Kominers (2016) find that nonpracticing entities (unlike practicing entities) sue firms that experience increases in their cash holdings. They interpret this interesting connection as evidence that—on average—nonpracticing entities act as patent trolls, but this evidence provides little information about the importance of these types of incentives in explaining the broader observed trends in patenting or innovation. While several other author teams have investigated various aspects of patent trolling (Abrams, Akcigit, and Grennan 2018; Lemley and Simcoe 2018; Feng and Jaravel forthcoming), the past literature has struggled to establish clear evidence that many or most nonpracticing entities are associated with welfare-reducing behavior.

Product Market Competition and International Trade

The impact of competition on innovation is theoretically ambiguous. On the negative side, Schumpeter (1942) argued that the desired reward for innovation is monopoly profits, and increasing competition tends to reduce those incentives. More broadly, settings with high competition may tend to imply lower future profits, which in turn will limit the internal funds available to finance research and development, which may be important given the financial frictions discussed above.

But there are also ways in which competition may encourage innovation. First, monopolists who benefit from high barriers to entry have little incentive to innovate and replace the stream of supernormal profits they already enjoy, in contrast to a new entrant who has no rents to lose (this is the "replacement effect," described in Arrow 1962). Second, tougher competition can induce managers to work harder and innovate more. Finally, capital and labor are often "trapped" within firms (for example, restricted by the costs of hiring employees or moving capital). If competition removes the market for a firm's product, it will be forced to innovate to redeploy these factors (Bloom et al. 2019). In some models, the impact of competition on innovation is plotted as an inverted U: when competition is low, the impact of greater competition on innovation first is positive, then becomes negative at higher levels of competition (see, for example, Aghion et al. 2005).

The bottom line is that the net impact of competition on innovation remains an open empirical question. However, existing empirical evidence suggests that competition typically increases innovation, especially in markets that initially have low levels of competition. Much of this literature focuses on import shocks that increase competition, such as China's integration in the global market following accession to the World Trade Organization in 2001. Shu and Steinwender (2019) summarize over 40 papers on trade and competition, arguing that in South America, Asia, and Europe, competition mostly drives increases in innovation (also see Blundell, Griffith, and Van Reenen 1999; Bloom, Draca, and Van Reenen 2016). In North America, the impact of import competition is more mixed; for example, Autor et al. (2016) argue that Chinese import competition reduced innovation in US manufacturing, although Xu and Gong (2017) argue these research and development employees displaced from manufacturing were re-employed in services, generating an ambiguous overall impact.

In addition to its effect on competition, trade openness can increase innovation by increasing market size, thus spreading the cost of innovation over a larger market (for example, Grossman and Helpman 1991). Moreover, trade leads to improved inputs and a faster diffusion of knowledge (for example, Diamond 1997; Keller 2004). Aghion et al. (2018) use shocks to a firm's export markets to demonstrate large positive effects on innovation in French firms. Atkin et al. (2017) implemented a randomized controlled trial to stimulate exports in small apparel firms in Egypt and found that exporting increases firms' productivity and quality. The benefits of superior imported inputs have been shown in a number of papers (including Goldberg et al. 2010; Fieler and Harrison 2018).

In our view, the policy prescription from this literature seems reasonably clear: greater competition and trade openness typically increase innovation. The financial costs of these policies are relatively low, given that there are additional positive impacts associated with policies that lower prices and increase choice. The downside is that such globalization shocks may increase inequality among people and places.

Targeting Small Firms

Financial constraints are often the rationale for focusing innovation policies on small firms. For example, in many countries the research and development tax credit is more generous for smaller firms (OECD 2018). Moreover, small firms appear to respond more positively to innovation and other business support policies than larger firms (Criscuolo et al. 2019). However, small-is-beautiful innovation policies have some problems as well. First, they can discourage firms from growing, as expanding beyond a certain point would disqualify them from their subsidies. Second, it is young firms, rather than small firms per se, that are most subject to these financial constraints.

One popular policy seeks to co-locate many smaller high-tech firms together. This may be in a high-density accelerator (intensive mentoring; highly selected) or incubator (less support; less selected) or in a larger science park. The idea is to generate agglomeration effects. There are several case studies and one metareview of this approach that suggest the overall impact of these policies is positive (Madaleno et al. 2018). Our sense, however, is that the evidence remains ambiguous here, despite the great popularity of these initiatives with local governments.

To the extent that financial frictions are impactful, removing constraints on the development of an active early-stage finance market (like angel finance or venture capital) might be a reasonable policy focus. In addition, focusing on subsidized loans for young firms, rather than general tax breaks or grants, may be more desirable.

More Moonshots? A Mission-Oriented Approach

Throughout this article, we have taken a pragmatic and marginal approach: given a policymaker's constraints, what is the best use of resources to stimulate growth through innovation? However, this approach may be too conservative given the scale of the current productivity problems.

Instead, some recent proposals have aimed at spurring a step change in productivity growth. Taking inspiration from the research and development efforts during World War II and Kennedy's Apollo "moonshot," "mission-oriented" R&D policies focus support on particular technologies or sectors. Many such mission-oriented policies in defense (such as DARPA, the Defense Advanced Research Projects Agency) and space (such as NASA, the National Aeronautics and Space Administration) have led to important innovations. Azoulay, Fuchs, et al. (2019) offer a detailed discussion of the "ARPA model"—an approach that has expanded beyond DARPA to HSARPA in the Department of Homeland Security, IARPA for US intelligence agencies, and ARPA-E in the Department of Energy. They argue that successful examples typically involve decentralization, active project selection (and a tolerance for inevitable failures), and organizational flexibility.

Economists are often skeptical of such sector-focused policies, because political decision-making may be more likely to favor sectors or firms that engage in lobbying and regulatory capture, rather than the most socially beneficial. Moreover, in many cases it may be hard to articulate an economic rationale behind these moonshots. Surely, the resources used in putting a man on the moon could have been directed more efficiently if the aim was solely to generate more innovation.

We see two main arguments for mission-based moonshots. First, moonshots may be justified in and of themselves. Technology to address climate change falls into this category: there is a pressing need to avoid environmental catastrophe, and obvious market failures exist around carbon emissions. The solution requires new technologies to help deliver decarbonization of the economy; moonshot strategies may result in the most valuable innovation in this case. Similar comments could be made of other social goals, such as disease reduction. It is important to remember that when the rate and direction of technological change are endogenous, conventional policies such as a carbon tax can be doubly effective (both by reducing carbon emissions and by generating incentives to direct research and development toward green technologies; see Acemoglu et al. 2012; Aghion et al. 2016).

Second, moonshots may be justified on the basis of political economy considerations. To generate significant extra resources for research, a politically sustainable vision needs to be created. For example, Gruber and Johnson (2019) argue that increasing federal funding of research as a share of GDP by half a percent—from 0.7 percent today to 1.2 percent, still lower than the almost 2 percent share observed in 1964 in Figure 1—would create a $100 billion fund that could jump-start new technology hubs in some of the more educated but less prosperous American cities (such as Rochester, New York, and Pittsburgh, Pennsylvania). They argue that such a fund could generate local spillovers and, by alleviating spatial inequality, be more politically sustainable than having research funds primarily flow to areas with highly concentrated research, such as Palo Alto, California, and Cambridge, Massachusetts.

Of course, it is difficult to bring credible econometric evidence to bear on the efficacy and efficiency of moonshots. We can discuss historical episodes and use theory to guide our thinking, but moonshots are, by nature, highly selected episodes with no obvious counterfactuals.

Conclusions

Market economies are likely to underprovide innovation, primarily due to knowledge spillovers between firms. This article has discussed the evidence on policy tools that aim to increase innovation.

We condense our (admittedly subjective) judgements into Table 2, which could be used as a toolkit for innovation policymakers. Column 1 summarizes our read of the quality of the currently available empirical evidence in terms of both the quantity

Table 2
Innovation Policy Toolkit

Policy	*Quality of evidence (1)*	*Conclusiveness of evidence (2)*	*Net benefit (3)*	*Time frame (4)*	*Effect on inequality (5)*
Direct R&D grants	Medium	Medium	💡💡	Medium run	↑
R&D tax credits	High	High	💡💡💡	Short run	↑
Patent box	Medium	Medium	Negative	NA	↑
Skilled immigration	High	High	💡💡💡	Short to medium run	↓
Universities: incentives	Medium	Low	💡	Medium run	↑
Universities: STEM supply	Medium	Medium	💡💡	Long run	↓
Trade and competition	High	Medium	💡💡💡	Medium run	↑
Intellectual property reform	Medium	Low	Unknown	Medium run	Unknown
Mission-oriented policies	Low	Low	💡	Medium run	Unknown

Source: The authors.
Notes: This is our highly subjective reading of the evidence. Column 1 reflects a mixture of the number of studies and the quality of the research design. Column 2 indicates whether the existing evidence delivers any firm policy conclusions. Column 3 is our assessment of the magnitude of the benefits minus the costs (assuming these are positive). Column 4 delineates whether the main benefits (if there are any) are likely to be seen in the short run (roughly, the next three to four years) or in the longer run (roughly ten years or more); NA means not applicable. Column 5 lists the likely effect on inequality.

of papers and the credibility of the evidence provided by those studies. Column 2 summarizes the conclusiveness of the evidence for policy. Column 3 scores the overall benefits minus costs (that is, the net benefit), in terms of a light bulb ranking where three is the highest. This ranking is meant to represent a composite of the strength of the evidence and the magnitude of average effects. Columns 4 and 5 are two other criteria: first, whether the main effects would be short term (say, within the next three to four years), medium term, or long term (approximately ten years or more), and second, the likely effects on inequality. Different policymakers (and citizens) will assign different weights to these criteria.

In the short run, research and development tax credits and direct public funding seem the most effective, whereas increasing the supply of human capital (for example, through expanding university admissions in the areas of science, technology, engineering, and mathematics) is more effective in the long run. Encouraging skilled immigration has big effects even in the short run. Competition and open trade policies probably have benefits that are more modest for innovation, but they are cheap in financial terms and so also score highly. One difference is that R&D subsidies and open trade policies are likely to increase inequality, partly by increasing the demand for highly skilled labor and partly, in the case of trade, because some communities will endure the pain of trade adjustment and job loss. In contrast, increasing the supply of highly skilled labor is likely to reduce inequality by easing competition for scarce human capital.

Of course, others will undoubtedly take different views on the policies listed in Table 2. Nevertheless, we hope that this framework at least prompts additional debate over what needs to be done to restore equitable growth in the modern economy.

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