ISSN 2042-2695

CENTRE for ECONOMIC PERFORMANCE

CEP Discussion Paper No 1634

July 2019

A Toolkit of Policies to Promote Innovation

Nicholas Bloom
John Van Reenen
Heidi Williams

THE LONDON SCHOOL OF ECONOMICS AND POLITICAL SCIENCE

ESRC ECONOMIC & SOCIAL RESEARCH COUNCIL

Abstract
Economic theory suggests that market economies are likely to under-provide innovation due to the public good nature of knowledge. Empirical evidence from the US and other advanced economies supports this idea. We summarize the pros and cons of different policy instruments for promoting innovation and provide a basic "toolkit" describing which policies are most effective, based on our reading of the evidence. In the short-run, R&D tax credits or direct public funding seem the most productive, but in the longer-run increasing the supply of human capital (e.g. relaxing immigration rules or expanding university STEM admissions) are likely more effective.

Key words: Innovation, R&D, intellectual property, tax, competition
JEL Codes: O31; O32

This paper was produced as part of the Centre's Growth Programme. The Centre for Economic Performance is financed by the Economic and Social Research Council.

For helpful comments on earlier drafts we would like to thank the editors (Tim Taylor, Enrico Moretti and Gordon Hanson) as well as Bronwyn Hall, Ben Jones, Josh Lerner, Petra Moser and Jim Poterba. Research reported in this publication was supported in part by the Sloan Foundation; SRF; Schmitt Sciences; the Economic and Social Research Council; and the National Institute on Aging and the NIH Common Fund, Office of the NIH Director, through Grant U01-AG046708 to the National Bureau of Economic Research (NBER); the content is solely the responsibility of the authors and does not necessarily represent the official views of the NIH or NBER.
Nicholas Bloom, Stanford University, NBER and Centre for Economic Performance, London School of Economics. John Van Reenen, MIT, NBER and Centre for Economic Performance, London School of Economics. Heidi Williams, Stanford University and NBER.

Published by
Centre for Economic Performance
London School of Economics and Political Science
Houghton Street
London WC2A 2AE

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or by any means without the prior permission in writing of the publisher nor be issued to the public or circulated in any form other than that in which it is published.

Requests for permission to reproduce any article or part of the Working Paper should be sent to the editor at the above address.

© N. Bloom, J. Van Reenen and H. Williams, submitted 2019.

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 further from the technological frontier, catch-up growth is a viable option, but this cannot be the case for leading-edge economies such as the US, Japan and the nations of Western Europe. For countries such as these, what are the most effective policies for stimulating 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, how would we advise them? 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 property policies, and pro-competition 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 US, many firms are well behind the technological frontier, and helping these firms catch up -- for example, by improving management practices – would likely be 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 move to the obvious question: why should a policymaker spend any resources at all on innovation?

Some Background Facts[1]

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

In recent years, around 13% of US R&D 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. Reflecting that distribution of federal funds across fields, the top agencies supporting federally funded academic R&D are the Department of Health and Human Services, the Department of Defense, and the National Science Foundation.

The statistics above all focus on R&D spending, but of course another set of metrics of innovative activity focus on the scientific workforce. These suggest that the fraction of workers who are researchers grew through 2000 in the US, but has been stable between 0.7 and 0.9 percent since. The EU has a similar fraction and Japan is closer to 1 percent. The most dramatic change over that period has been in South Korea, which increased from around 0.5 percent in 2000 to nearly 1.4 percent in 2015.

Another metric relevant to the size of the scientific workforce in the US is the number of temporary work visas issued in categories that cover high-skill workers: J-1 (exchange visitors),

[1] Unless otherwise noted, all data and facts in this section – and later in the paper – are drawn from the National Science Board's *Science & Engineering Indicators 2018*.

H-1B, and L-1 (intracompany transferee) visas. Between 1991 and 2015, the primary increase in these categories has been in J-1 visas (exchange visitors), 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; note that the 65,000 H-1B cap was in place over that entire period, implying that the growth was driven by H-1B's to universities, non-profit research facilities, and government research facilities, all of which are exempt from the H-1B annual 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 (R&D) spending are typically richer (for example, Jones 2015). However, standard economic theory also 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 (for example, the Anglo-French supersonic jet, Concorde; see Lerner 2005 for one discussion). On the other hand, there are also many examples of impressive inventions built on government-sponsored research and development, such as jet engines, radar, nuclear power, GPS and the Internet (Janeway, 2012, and Mazzucato, 2013).

The central market failure that economists have focused on in justifying government intervention in innovation markets is knowledge spillovers. If one firm creates something truly innovative, this knowledge may spill over to other firms through copying or by learning from the original research – without having to pay the full R&D 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 R&D expenditures in a market economy can be either too low or too high, depending on the net size of knowledge spillovers and so-called product market spillovers. The key idea behind product market spillovers is that private incentives can lead to over-investment in research and development 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 me too 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 a case study approach is Griliches (1958), which estimates the social rate of return realized by to public and private investments in hybrid corn research (see Comin and Hobijn, 2010, for more recent case studies of diffusion). He 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." While we 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.

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 R&D investment. 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 quasi-experiments that influence research and development investments to identify the arrow of causality (for example, Bloom et al., 2013).

The key idea in using patent citations to measure spillovers is that each patent cites other patents, in addition to associated publications, all of which form the basis of "prior art" – existing innovations that enabled that particular patent. Trajtenberg (1990) and Jaffe, Henderson, and Trajtenberg (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 (for example, Griffith et al., 2011).

One challenge arising with the production function approach is how to find 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 knowledge spillovers are mediated. Firms less distant from each other in this dimension will be more affected by the R&D efforts of their peers – e.g. technological distance as revealed from past patenting classes (Jaffe 1986), geographical distance between corporate R&D labs, or 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 US, for example, recent estimates in Lucking et al. (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%, compared to private returns of around 15%, suggesting the need 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 R&D because potential innovators expect to be able to appropriate more of the benefits. However, 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 the US, which has a strong system of intellectual property rights by international standards.

There are other potential justifications for R&D subsidies in addition to spillovers, 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 do often 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. Hence, effective government policies to address financial constraints involve not just financial support for firms but also a mechanism to accurately identify and select higher quality investments, which is typically difficult.

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-competition 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, therefore, be written off in the year in which they occur. By contrast, investments in long-lasting assets like plants, equipment, and buildings must be written-off over a multi-year 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 corporate tax rate, then every $1 of R&D expenditure reduces corporate taxes by 20 cents. However, if a government allows a 150 percent rate of super-deduction, and again assuming a corporate tax rate of 20 percent, then $1 of R&D spending would reduce corporate taxes by 30 cents. President Reagan introduced the first Research and Experimentation Tax Credit in the US 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 they examined provide some material level of R&D tax generosity. The US federal R&D tax credit is in the bottom 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 tax credit is based on the incremental *increase* in a firm's R&D over a historically defined base level, rather than a subsidy based on the total amount of R&D spending. In countries like France, Portugal and Chile with the most generous provisions, 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 research and development 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 market demand, rather than by tax incentives. There are now a large number of studies examining changes in the rules determining the generosity of tax incentives using a variety of data and methodologies (for a survey, see Becker, 2015). Many early studies used cross-country 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 using a regression discontinuity design (Dechezlepretre 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 re-label existing expenditures as "research and development" to take advantage of the more generous tax breaks. Chen et al. (2018), for example, found substantial re-labelling 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 2018 and Akcigit et al. 2018; for the UK, see Dechezlepretre et al. 2016; for China, see Chen et al. 2017; and for Norway, see Bøler et al. 2015).

Another concern is that research and development tax credits may not raise aggregate R&D but rather simply cause a relocation towards geographical areas with more generous fiscal incentives and away from geographic areas with less generous incentives. US policymakers may not care so much if tax credits shifts activity from, say, Europe to the US, but Americans should care if state-specific credits simply shift around activity from one state to another.

There are wide varieties of local innovation policies explicitly trying to relocate innovative activity across places within the US 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 those areas who 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 et al. (2017) document a similar relocation pattern in an international dimension. Wilson (2009) and Bloom and Griffith (2005) also document some evidence of relocation in response to R&D 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 non-relocating incumbents. Overall, the conclusion from the literature is that despite some relocation across place, the aggregate effect of R&D tax credits at the national level on both the volume of R&D and 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 intellectual property tax incentives) were used in 16 OECD countries (Guenther 2017). Although patent box schemes purport to be a way of incentivizing R&D, 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, 2011), 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 and effective (see Choi, 2019) for governments to use patent box policies to collect footloose tax revenues, such policies do not have much effect on the real location or the quantity of either research and development 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 R&D tax credits (where it is harder to manipulate the stated location of research labs), patent boxes should be discouraged.

Government Research Grants

A disadvantage of tax-based support is that tax policies are difficult to target at 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 e.g. basic R&D such as that performed in universities rather than more applied R&D. 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, growth, or other outcomes). 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 that just 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 et al. (2019a) 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 (SBIR) 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 go 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, Research Triangle in North Carolina, and others). 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 R&D 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 UK's Synchrotron Diamond Light Source appeared to do this (Helmers and Overman, 2013), but this seems in that case to have occurred mainly through relocation of research activity within the US rather than by spurring an increase in aggregate research.

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

[2] Jaffe and Lerner (1990) 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 innovation specifically. Hausman (2018) and Andrews (2018) also find positive effects of universities on US innovation.

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 to 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 R&D by reducing its price 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 the total number of total 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, also 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 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 which 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

---

[3] This insight also suggests that general equilibrium effects of a 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 et al, 2002). See Atkeson and Burstein (2018) for an attempt to put these together in a macro model that shows large long-run welfare effects of innovation policies.

of inventors. For example, 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 is challenging 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 STEM qualifications, 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 STEM majors, 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 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 US 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 or more, but constitute 26 percent of the STEM 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, using state panel data from 1940-2000, Hunt and Gauthier-Loiselle (2010) document that a one-percentage point increase in immigrant college graduates' population share increases patents per capita by 9 to 18 percent. 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] 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 (Hunt and Gauthier-Loiselle, 2010, also estimate large spillovers).

The US federal government's introduction of immigration quotas with varying degrees of strictness in the early 1920s – for example, Southern Europeans, like Italians, were more strongly affected than Northern Europeans, like Swedes -- has been used to document how exogenous reductions of immigration damaged innovation. Moser and San (2019) use rich biographical data to show that these quotas (perhaps inadvertently) discouraged Eastern and Southern European scientists from coming to the US and 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 relaxing 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 becoming successful inventors. Bell et al. (2019), for example, document that US children born into the top one 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 of 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.

[4] Using H1-B visa lotteries, Doran, Gelber and Isen (2015) estimate smaller effects than Kerr and Lincoln (2010).By contrast, Borjas and Doran (2015) 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; note that their findings may reflect a feature specific to academic publishing where there are (in the short run) constraints on the size of academic journals and departments. Moser, Voena, and Waldinger (2014) estimate that most of the effect of immigration on innovation came from new entry.

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. While 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) 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. While 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 here focus on two specific areas currently under active policy debate.

First, what types of technologies "should" be patent-eligible? The US Patent and Trademark Office (USPTO) is tasked with awarding patent rights to inventions that are novel, non-obvious, 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 U.S. 593 [2010]), medical diagnostic tests (*Mayo Collaborative Services v. Prometheus Laboratories, Inc.*. 566 U.S. 66 [2012]), human genes (*Association for Molecular Pathology v. Myriad Genetics, Inc.*, 569 U.S. 576 [2013]), and software (*Alice Corp. v. CLS Bank International*, 573 U.S. 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 innovation more than it encourages it. 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 2017).

Second, many current debates about patent reform center around "patent trolls," which is a pejorative name given to certain "non-practicing 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 harms product quality nor increases prices. On the other hand, Cohen, Gurun, and Kominers (2016) find that non-practicing entities (unlike practicing entities) sue firms that experience increases in their cash holdings. They interpret this interesting connection as evidence that – on average –non-practicing 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 of patenting or innovation. While several other author teams have investigated various aspects of patent trolling (Abrams, Akcigit, and Grennan 2018; Feng and Jaravel, forthcoming; Lemley and Simcoe 2018), the past literature has struggled to establish clear evidence that many or most non-practicing 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 of 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 R&D, 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 super-normal 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., 2017). In some models, the impact of competition on innovation is plotted as an inverted-U: when competition is low, the impact on innovation is first positive, and then becomes negative at higher levels of competition (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 (2018) 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 et al. 1999; Bloom et al., 2016). In North America, the impact of import competition is more mixed; for example, Autor et al. (2017) argue that Chinese import competition reduced innovation in US manufacturing, although Xu and Gong (2017) argue these R&D 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, which spreads 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, Keller 2004; Diamond 1997). 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 control 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; Bøler et al. 2015; Fieler et al. 2018).

In our view, the policy prescription from this literature seems reasonably clear – greater competition and trade openness typically increases 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 between people and places.

Targeting Small Firms

Financial constraints are often the rationale for focusing innovation policies on small firms. For example, the R&D tax credit in many countries 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 growth 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 is to co-locate many smaller high tech firms together. This may be in a high-density accelerator (intensive mentoring and highly selected) or incubator (less support and less selected) or in a larger science park. The idea is to generate agglomeration effects. There are several case studies and one meta-review is quite positive (Madaleno et al. 2018). Our sense, however, is that the evidence is still 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 small firms, rather than general tax breaks or grants, may be more desirable.

More Moonshots? A mission-oriented approach

Throughout this paper, 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.

Recently, there have been some proposals aimed instead at spurring a step change in productivity growth. Taking inspiration from the R&D efforts during the Second World War and Kennedy's Apollo "moonshot" through NASA. "Mission oriented" R&D policies focus support on particular technologies or sectors (which contrasts with general tax or IP policies which are broadly neutral across technologies and industries). Many such mission oriented policies in defense (like the Defense Advanced Research Projects Agency, or DARPA) and space (like the National Aeronautics and Space Administration, or NASA) have led to important innovations.[5]

Economists are often skeptical of such sector-focused policies, because political decision-making may be more likely to favor sectors or firms which engage in lobbying and regulatory capture, rather than targeting the most socially beneficial technologies. 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. Climate change falls into this category – there is a pressing need to avoid environmental catastrophe and obvious market failures in carbon emission. The solution requires new technologies to help deliver de-carbonization of the economy, so we should consider the best innovation policies to help deliver this. 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 is endogenous, conventional policies like a carbon tax can be doubly effective (both by reducing carbon emissions and generating incentives to direct R&D towards green technologies (see Acemoglu et al., 2012; Aghion et al., 2016).

[5] Azoulay et al. (2019b) 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 in 2006, and ARPA-E in the Department of Energy – and argue that successful examples typically involve decentralization, active project selection (and a tolerance for inevitable failures), and organizational flexibility.

Second, moonshots may be justified based on political economy considerations. In order 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% today to 0.12%, still lower than the 2% share observed in 1964 – would create a new $100 billion fund which could jumpstart new technology hubs in some of the more educated but less prosperous American cities (e.g. Rochester, NY and Pittsburg, PA). Such a fund could generate local spillovers and, by alleviating spatial inequality (a source of rising populism), be more politically sustainable than having federal research funds primarily flow to Palo Alto and Cambridge.

Of course, by design 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 highly selected episodes with no obvious counterfactual.

Conclusions

Market economies are likely to under-provide innovation, primarily due to fact that knowledge spills over between firms. This article has discussed the evidence on policy tools which aim to increase innovation.

We condense our (admittedly subjective) judgements into Table 2, which could be used as a toolkit for innovation policymakers. Column 2 summarizes our read of the quality of the currently available empirical evidence in terms of both quantity of papers and credibility of the evidence provided by those studies. Column 3 summarizes the conclusiveness of the evidence – for example, although there are some credible approaches for estimating the impact of intellectual property, the policy implications of the available findings are unclear. Column 4 scores the overall benefits minus costs, in terms of a light bulb ranking where three is the highest; this is meant to represent a composite of the strength of the evidence as well as the magnitude of average effects. Columns 5 and 6 are two other criteria: first, whether the main effects would be short-term, medium term or long-term; 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 or direct public funding seem the most effective, whereas increasing the supply of human capital (for example, through expanding university STEM admissions) is more effective in the long-run. Skilled immigration has big effects even in the short-run. Competition and trade policies probably have benefits that are more modest on innovation, but are cheap in financial terms and so also score highly. One difference is that R&D subsidies and trade policies are likely to increase inequality, partly through 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. By 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.

References

Abrams, David, Ufuk Akcigit, and Jillian Grennan. 2018. "Patent Value and Citations: Creative Destruction or Strategic Disruption?" University of Pennsylvania, Institute for Law & Econ Research Paper No. 13-23.

Acemoglu, Daron, Philippe Aghion, Leonardo Bursztyn, and David Hemous. 2012. "The Environment and Directed Technical Change." American Economic Review, 102 (1), 131–166.

Aghion, Philippe, Nicholas Bloom, Richard Blundell, Rachel Griffith, and Peter Howitt. 2005. "Competition and Innovation: An Inverted U Relationship?" Quarterly Journal of Economics, 120(2), 701-728.

Aghion, Philippe, Antoine Dechezlepretre, David Hemous, Ralf Martin and John Van Reenen. 2016. "Carbon Taxes, Path Dependency and Directed Technical Change: Evidence from the Auto Industry." Journal of Political Economy, 124(1), 1-51.

Aghion, Philippe, Antonin Bergeaud, Matthieu Lequien, and Marc Melitz. 2018. "The Impact of Exports on Innovation: Theory and Evidence." NBER Working Paper 24600.

Akcigit, Ufuk, Salome Baslandze and Stefanie Stantcheva. 2017. "Taxation and the International Mobility of Inventors." American Economic Review, 106(10), 2930-2981.

Akcigit, Ufuk, John Grigsby, Tom Nicholas and Stefanie Stantcheva. 2018. "Taxation and Innovation in the 20th Century." NBER Working Paper 24982.

Andrews, Michael. 2017. "How do institutions of higher education affect local invention? Evidence from the establishment of U.S. colleges." mimeo.

Arrow, Kenneth. 1962 "Economic Welfare and Allocation of Resources for Invention." in National Bureau of Economic Research, 609–626 The Rate and Direction of Inventive Activity: Economic and Social Factors, Princeton, NJ: Princeton University Press.

Atkeson, Andrew, and Burstein, Ariel (2018), "Aggregate implications of innovation policy", forthcoming Journal of Political Economy

Atkin, David, Amit Khandelwal, and Adam Osman. 2017. "Exporting and Firm Performance: Evidence from a Randomized Experiment." Quarterly Journal of Economics, 132(2), 551-615.

Autor, David, David Dorn, Gordon Hanson, Gary Pisano, and Pian Shu. 2017. "Foreign Competition and Domestic Innovation: Evidence from U.S. Patents." NBER Working Paper No. 22879

Azoulay, Pierre, Joshua S. Graff Zivin, Danielle Li, and Bhaven N. Sampat. 2019a. "Public R&D Investments and Private Sector Patenting: Evidence from NIH Funding Rules." Review of Economic Studies, 86, 1, 117–152.

Azoulay, Pierre, Erica Fuchs, Anna Goldstein, and Michael Kearney. 2019b "Funding Breakthrough Research: Promises and Challenges of the ARPA Model" Innovation Policy and the Economy, volume 19, Joshua Lerner and Scott Stern (eds).

Becker, Bettina. 2015. "Public R&D policies and private R&D investment: A survey of the empirical evidence." Journal of Economic Surveys, 29(5) 917–942.

Belenzon, Sharon and Mark Schankerman. 2013. "Spreading the word: geography, policy and knowledge spillovers." Review of Economics and Statistics, 95 (3), 884-903.

Bell, Alexander, Raj Chetty, Xavier Jaravel, Neviana Petkova, and John Van Reenen. 2019. "Who Becomes an Inventor in America? The Importance of Exposure to Innovation." Quarterly Journal of Economics, forthcoming.

Bernstein, Shai, Rebecca Diamond, Timothy McQuade and Beatriz Pousada. 2018. "The Contribution of High-Skilled Immigrants to Innovation in the United States." Stanford mimeo.

Bianchi, Nicola, and Michela Giorcelli. 2018. "Reconstruction aid, public infrastructure, and economic development." Mimeo.

Bloom, Nicholas, Griffith, Rachel, and John Van Reenen. 2002. "Do R&D tax credits work? Evidence from a panel of countries, 1979–1997." Journal of Public Economics, 85(1), 1-31.

Bloom, Nicholas, Mark Schankerman, and John Van Reenen. 2013. "Identifying technology spillovers and product market rivalry." Econometrica, 81(4) 1347-1393.

Bloom, Nicholas and Rachel Griffith. 2005. "The Internationalization of UK R&D." Fiscal Studies, 22(3), 337-355.

Bloom, Nicholas, Paul Romer, Stephen J. Terry, and John Van Reenen. 2017. "A Trapped Factors Model of Innovation." CEP Discussion Paper 1261.

Blundell, Richard, Rachel Griffith, and John Van Reenen. 1999. "Market share, market value and Innovation: Evidence from British Manufacturing Firms." Review of Economic Studies, 66(3), 228, 529-554.

Boldrin, Michele, and David K. Levine. 2013. "The case against patents." Journal of Economic Perspectives, 27(1), 3-22.

Bøler, Esther Ann, Andreas Moxnes, and Karen Helene Ulltveit-Moe. 2015. "R&D, International Sourcing, and the Joint Impact on Firm Performance." American Economic Review, 105(12), 3704-3729.

Borjas, George J., and Kirk B. Doran. 2012. "The Collapse of the Soviet Union and the Productivity of American Mathematicians." Quarterly Journal of Economics, 127 (3), 1143–1203.

Chen, Zhao, Zhikuo Liu, Juan Carlos Suarez-Serrato, and Daniel Xu. 2018. "Notching R&D Investment with Corporate Income Tax Cuts in China." NBER Working Paper No. 24749.

Choi, Jane. 2019. "How much do tax rates matter for the location of Intellectual Property" MIT mimeo

Cohen, Lauren, Umit G. Gurun, and Scott Duke Kominers. 2016. "Shielded Innovation." Mimeo.

Comin, Diego, and Bart Hobijn. 2010. "An Exploration of Technology Diffusion." American Economic Review 100(5): 2031-59

Criscuolo, Chiara, Ralf Martin, Henry Overman, and John Van Reenen. 2019. "Some causal effects of an industrial policy." American Economic Review, 109(1), 48-85.

Davis, Steven, John Haltiwanger and Scott Schuh. 1996. "Small Business and Job Creation: Dissecting the Myth and Reassessing the Facts." Small Business Economics, 8(4), 297-315.

Dechezlepretre, Antoine, Elias Einio, Ralf Martin, Kieu-Trang Nguyen and John Van Reenen. 2016. "Do Fiscal Incentives increase innovation? An RD Design for R&D." CEP Discussion Paper 1413.

Diamond, Jared. 1997. Guns, Germs and Steel, New York: W.W. Norton.

Doran, Kirk and Chungeun Yoon. 2018. "Immigration and Invention: Evidence from the Quota Acts." University of Notre Dame mimeo.

Doran, Kirk, Alex Gelber, and Adam Isen. 2015. "The effects of high-skilled immigration policy on firms: Evidence from H-1B visa lotteries." NBER Working Paper 20668.

Feng, Josh, and Xavier Jaravel. 2018. "Crafting Intellectual Property Rights: Implications for Patent Assertion Entities, Litigation, and Innovation." Unpublished.

Fieler, Ana Cecilia and Ann Harrison. 2018. "Escaping import competition and downstream tariffs." NBER Working Paper No. 24527.

Gaessler, Fabian, Bronwyn H. Hall, and Dietmar Harhoff. 2018. "Should there be lower taxes on patent income?" IFS Working Paper W18/19.

Goldberg, Pinelopi Koujianou, Amit Kumar Khandelwal, Nina Pavcnik, and Petia Topalova. 2010. "Imported intermediate inputs and domestic product growth: evidence from India." Quarterly Journal of Economics, 125(4), 1727-1767.

Goolsbee, Austan. 1998. "Does government R&D policy mainly benefit scientists and engineers?" American Economic Review, 88(2), 298-302.

Griffith, Rachel, Helen Miller and Martin O'Connell. 2014. "Ownership of Intellectual Property and Corporate Taxation" Journal of Public Economics, 112, 12-23.

Griffith, Rachel, Simon Lee and John Van Reenen. 2011. "Is distance dying at last? Falling

Home bias in fixed effects models of patent citations” *Quantitative Economics*, 2, 211-249

Griliches, Zvi. 1958. “Research costs and social returns: hybrid corn and related innovations.” Journal of Political Economy, 66, 419.

Griliches, Zvi. 1992. “The search for R&D spillovers.” Scandinavian Journal of Economics, 94, 29-47.

Guenther, Gary. 2017. “Patent boxes: A Primer.” Congressional Research Service.

Grossman, Gene and Elhanan Helpman. 1991. Innovation and Growth in the Global Economy. MIT Press, Cambridge MA.

Haber, Stephen, and Ross Levine. June 30, 2014. “The Myth of the Wicked Patent Troll.” Wall Street Journal.

Hall, Bronwyn and Josh Lerner. 2010. “The Financing of R&D and Innovation” in Handbook of the Economics of Innovation. Vol. 1, edited by Bronwyn Hall and Nathan Rosenberg. Elsevier.

Hausman, Naomi (2018) “University Innovation and Local Economic Growth”, Hebrew University mimeo

Howell, Sabrina T. 2017. “Financing Innovation: Evidence from R&D Grants.” American Economic Review, 107(4), 1136-64.

Hunt, Jennifer, and Marjolaine Gauthier-Loiselle. 2010. "How Much Does Immigration Boost Innovation?" American Economic Journal: Macroeconomics, 2 (2), 31-56.

Hvide, Hans K. and Benjamin F. Jones. 2018. “University Innovation and Professor’s Privilege.” American Economic Review, 108(7), 1860-1898.

Jacob, Brian and Lars Lefgren. 2011. “The Impact of Research Grant Funding on Scientific Productivity.” Journal of Public Economics, 95(9-10), 1168-1177.

Jaffe, Adam. 1986. "Technological Opportunity and Spillovers of R&D: Evidence from Firms' Patents, Profits and Market Value." American Economic Review, 76, 984-1001.

Jaffe, Adam. 1989. “Real Effects of Academic Research.” American Economic Review, 79(5), 957-70.

Jaffe, Adam, Manuel Trajtenberg, and Rebecca Henderson, “Geographic Localization of Knowledge Spillovers as Evidenced by Patent Citations,” Quarterly Journal of Economics, 1993, 108 (3), 577–598.

Janeway, William. 2012. Doing Capitalism in the Innovation Economy: Markets, Speculation and the State. Cambridge University Press.

Jones, Charles. 2015. "The Facts of Economic Growth." Chapter 2 in John Taylor and Harald Uhlig (eds.), Handbook of Macroeconomics Volume 2A, North Holland.

Keller, Wolfgang. 2004. "International Technology Diffusion." Journal of Economic Literature, 42(3), 752-782.

Kerr, William and William Lincoln. 2010. "The Supply Side of Innovation: H-1B Visa Reforms and U.S. Ethnic Invention." Journal of Labor Economics, 28(3), 473-508.

Lach, Saul and Mark Schankerman. 2008. "Incentives and Invention in Universities." Rand Journal of Economics, 39(2), 403-33.

Lemley, Mark A., and Timothy Simcoe. 2018. "How Essential are Standard-Essential Patents?" Stanford Public Law Working Paper.

Lerner, Josh. 2005. The Boulevard of Broken Dreams. Princeton: Princeton University Press.

Li, Xing, Megan MacGarvie, and Petra Moser. 2018. "Dead Poet's Property – How Does Copyright Influence Price?" RAND Journal of Economics, 49(1), 181-205.

Litan, Robert, Lesa Mitchell, and E.J. Reedy. 2007. "Commercializing University Innovations: Alternative Approaches." Innovation Policy in the Economy, 8, 31-57.

Lucking, Brian, Nicholas Bloom, and John Van Reenen. 2018. "Have R&D spillovers changed?" CEP Discussion Paper 1548.

Lucking, Brian. 2018. "Do R&D Tax Credits Create Jobs?", Stanford mimeo.

OECD. 2018. Review of National R&D Tax Incentives and Estimates of R&D Tax Subsidy Rates, Paris: OECD.

Madaleno, Margarida, Max Nathan, Henry Overman and Sevrin Waights. 2018. "Incubators, Accelerators and Regional Economic Development" CEP Discussion Paper 1575

Mazzucato, Mariana. 2013. The Entrepreneurial State: Debunking Public vs. Private Sector Myths, Anthem Press.

Moretti, Enrico and Daniel J. Wilson. 2017. "The effect of state Taxes on the geographical location of top earners: Evidence from star scientists." American Economic Review, 107(7), 1858-1903.

Moretti, Enrico, Claudia Steinwender, John Van Reenen and Patrick Warren. 2019. "The Intellectual Spoils of War? Defense R&D, Productivity and International Technology

Spillovers.” MIT mimeo.

Moser, Petra and Shmuel San. 2019. “Immigration, Science, and Invention: Evidence from the 1920s Quota Acts” NYU mimeo

Romer, Paul M. 2001. “Should the Government Subsidize Supply or Demand in the Market for Scientists and Engineers?” Innovation Policy and the Economy, 1, 221-252.

Schumpeter, Joseph. 1942. Capitalism, Socialism and Democracy, New York: Basic Books.

Shambaugh, Jay, Ryan Nunn, and Becca Portman. 2017. “Eleven Facts about Innovation and Patents,” Hamilton Project Report.

Toivanen, Otto and Lotta Väänänen. 2016. “Education and invention.” Review of Economics and Statistics, 98(2), 382-396.

Trajtenberg, Manuel. 1990, “A penny for your quotes: patent citations and the value of innovations”, Rand Journal of Economics, vol 21 (1), 172-187.

Valero, Anna and John Van Reenen. 2019. “The Economic Impact of Universities: Evidence from Across the Globe.” Economics of Education, 68, 53-67.

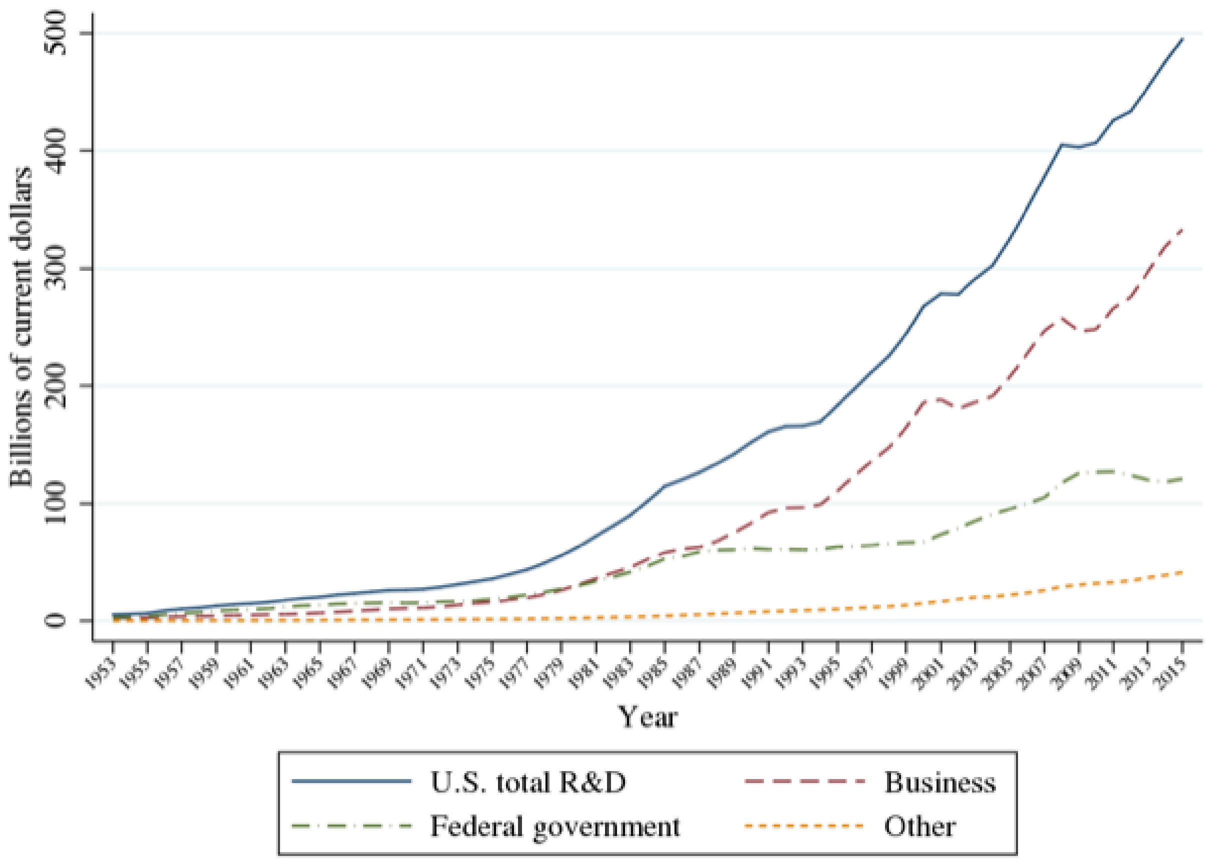
Warda, Jacek (2001) “Measuring the Value of R&D Tax Treatment in OECD Countries”, STI Review 27, Paris: OECD

Williams, Heidi. 2017. “How Do Patents Affect Research Investments?” Annual Reviews of Economics, 9: 441-469.

Wilson, Daniel J. 2009. “Beggar thy neighbor? The in-state, out-of-state and aggregate effects of R&D tax credits.” Review of Economics and Statistics, 91(2), 431-436.

Xu, Rui and Kaiji Gong. 2017. “Does Import Competition Induce R&D Reallocation? Evidence from the U.S.” IMF Working Paper 17/253.

Figure 1: US R&D, by source of funds: 1953-2015



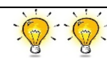
Notes: This figure displays data from Figure 4-1 of the National Science Board *Science and Engineering Indicators 2018*, Chapter 4. The original data are drawn from the National Science Foundation, National Center for Science and Engineering Statistics, National Patterns of R&D Resources (annual series).

Table 1: International comparison of R&D expenditures in 2015

Country	R&D expenditures (PPP $millions)	R&D/GDP (%)
United States	496,585.0	2.74
China	408,829.0	2.07
India	50,269.4	0.63
Japan	170,003.0	3.29
Germany	114,778.1	2.93
Russia	38l,135.5	1.1
Brazil	38,447.9	1.17
France	60,818.7	2.22
United Kingdom	46,259.8	1.7
Indonesia	2,130.3	0.08
OECD (average)	34,666.1	2.38

Notes: This table displays data on gross domestic expenditures on R&D (reported in purchasing power parity adjusted millions of dollars) and R&D as a share of GDP for the US, the nine other countries with the largest GDPs in 2015, and the OECD average (averaged over all 36 member countries as of 2015). These data are drawn from Table 4-5 of the National Science Board *Science and Engineering Indicators 2018*, Chapter 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 13 October 2017.

Table 2: Innovation Policy Toolkit

(1)	(2)	(3)	(4)	(5)	(6)
Policy	**Quality of evidence**	**Conclusiveness of evidence**	**Benefit - Cost**	**Time frame:**	**Effect on inequality**
Direct R&D Grants	Medium	Medium		Medium-Run	↑
R&D tax credits	High	High		Short-Run	↑
Patent Box	Medium	Medium	Negative	n/a	↑
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

Notes: This is our highly subjective reading of the evidence. Column (2), "quality," is a mixture of the number of studies and the quality of the research design. Column (3) is whether the existing evidence delivers any firm policy conclusions. Column (4) is our assessment of the magnitude of the benefits minus the costs (assuming these are positive). Column (5) is whether the main benefits are likely to be seen (if there are any) in the short run (roughly, the next 3-4 years) or longer. Column (6) is the likely effect on inequality.

CENTRE FOR ECONOMIC PERFORMANCE
Recent Discussion Papers

1633	Stephan E. Maurer Ferdinand Rauch	Economic Geography Aspects of the Panama Canal
1632	Nikhil Datta	Willing to Pay for Security: A Discrete Choice Experiment to Analyse Labour Supply Preferences
1631	Gabriel M. Ahlfeldt Volker Nitsch Nicolai Wendland	Ease Versus Noise: Long-Run Changes in the Value of Transport (Dis)amenities
1630	Grace Lordan Alistair McGuire	Widening the High School Curriculum to Include Soft Skill Training: Impacts on Health, Behaviour, Emotional Wellbeing and Occupational Aspirations
1629	Per-Anders Edin Tiernan Evans Georg Graetz Sofia Hernnäs Guy Michaels	Individual Consequences of Occupational Decline
1628	Pawel Bukowski Filip Novokmet	Between Communism and Capitalism: Long-Term Inequality in Poland, 1892-2015
1627	Thomas Sampson	Technology Gaps, Trade and Income
1626	Andrea Ichino Martin Olsson Barbara Petrongolo Peter Skogman Thoursie	Economic Incentives, Home Production and Gender Identity Norms
1625	Richard Murphy	Why Unions Survive: Understanding How Unions Overcome the Free-Rider Problem
1624	Natalie Chen Wanyu Chung Dennis Novy	Vehicle Currency Pricing and Exchange Rate Pass-Through

1623	Michael Amior Alan Manning	Commuting, Migration and Local Joblessness
1622	Rui Costa Swati Dhingra Stephen Machin	Trade and Worker Deskilling
1621	Jan-Emmanuel De Neve Clement Imbert Johannes Spinnewijn Teodora Tsankova, Maarten Luts	How to Improve Tax Compliance? Evidence from Population-wide Experiments in Belgium
1620	David S. Jacks Dennis Novy	Trade Blocs and Trade Wars during the Interwar Period
1619	Giulia Faggio Olmo Silva William C. Strange	Tales of the City: What Do Agglomeration Cases Tell Us About Agglomeration in General?
1618	Andrew Mountford Jonathan Wadsworth	Trainspotting: 'Good Jobs', Training and Skilled Immigration
1617	Marta De Philippis Federico Rossi	Parents, Schools and Human Capital Differences across Countries
1616	Michael Amior	Education and Geographical Mobility: The Role of Wage Rents
1615	Ria Ivandic Tom Kirchmaier Stephen Machin	Jihadi Attacks, Media and Local Hate Crime
1614	Johannes Boehm Swati Dhingra John Morrow	The Comparative Advantage of Firms

The Centre for Economic Performance Publications Unit
Tel: +44 (0)20 7955 7673 Email info@cep.lse.ac.uk
Website: http://cep.lse.ac.uk Twitter: @CEP_LSE