

Innovation and Human Capital Policy

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Abstract

If innovation is to be subsidized, a natural place to start is to act on the quantity and quality of the stock of human capital. Innovation, after all, begins with people. Simply stimulating the “demand side” through R&D tax incentives may only drive up the price, rather than the volume of research activity. However, increasing the supply of STEM human capital can both directly increase innovation and reduce its cost. This paper examines the evidence on alternative human capital policies for innovation including expanding the homegrown workforce, fostering immigration, boosting universities and reducing barriers to entry into inventor careers, especially for underrepresented groups. We argue that targeting high ability but disadvantaged potential inventors at an early age will have the largest long-run effects.

Keywords: Innovation, R&D, intellectual property, tax, competition

JEL Classification: O31, O32

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Introduction

Since the 1970s, U.S. productivity growth has slowed – reflected in falling total GDP growth from 4 percent in the post-war years, to under 3 percent from the mid-1970s, and to under 2 percent since 2000. The CBO projects growth in the mid-2020s of only 1.7 percent. 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 there are limits to such a strategy for leading-edge economies such as the US. Certainly, 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 (e.g. Bloom and Van Reenen, 2007). Nonetheless, we believe that sensible innovation policy design is a key part of the solution for revitalizing the US, and will lead to large long-run increases in welfare.

The attraction of human capital policies for innovation is that they act directly on the supply side, to increase the number of potential and actual innovators. Romer (2001) emphasized the advantage of supply side policies. “Demand side” policies such as tax credits and direct government R&D grants can be effective in increasing firms’ incentives to do more R&D – and there is an impressive body of micro-economic research on this (see Appendix A). However, if the supply of R&D workers is very inelastic then the risk is that the increase in demand merely drives up the equilibrium cost of R&D without increasing its volume. In other words, the incidence of the subsidy is in price rather than quantity. This is what Goolsbee (1998) found in aggregate US data –scientists’ wages rose substantially with increased Federal R&D spending. Microeconomic analysis might miss this, as the wage increase is a general equilibrium effect, absorbed away by the time dummies typically included in the evaluations. Furthermore, since R&D workers are above median pay employees, this type of demand side policy could increase inequality as well as providing little in the way of aggregate innovation.

The elasticity of supply is unlikely to be completely fixed (especially when we consider immigration into the US – see below). However, in the short-run, supply could be relatively inelastic, so these concerns are real.

A supply side increase in the quantity of R&D workers does not carry such a risk. Unless the new workers are dramatically less productive than the existing stock, we would expect a direct increase in innovation. Furthermore, the increase in supply should reduce the equilibrium cost of R&D; a successful supply side policy provides a further indirect boost to the amount of innovation, as firms face lower R&D costs.

The structure of the paper is that we provide some background R&D and workforce statistics in Section I; in Section II, we discuss the rationale for innovation subsidies; in Section III, we discuss the evidence on four types of human capital supply policies. Section IV offers some concluding comments.

I. Background: R&D and the Scientific Workforce¹

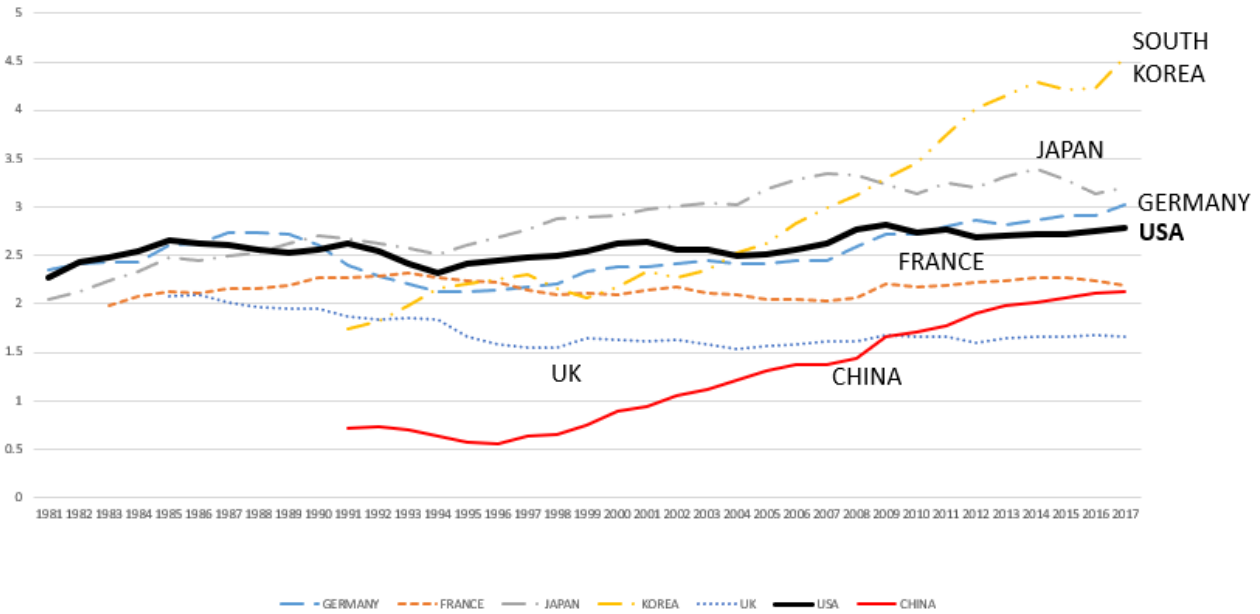
In 2015, spending on research and development (R&D) performed in the US was just over \$495 billion. Figure 1 shows research and development (R&D) spending as a fraction of GDP for major industrialized countries. The U.S. spends more on R&D than any other, accounting for roughly 28% of global R&D spending (\$1.918 trillion) - see National Science Board (2018).

Over time, however, the picture is less rosy. The U.S. has maintained an R&D to GDP ratio of 2.5% to 2.7% since 1981. By contrast, other countries, particularly in Asia (Japan, South Korea and most recently and spectacularly, China), have been devoting increasing amounts of national income to R&D. Furthermore, although U.S. R&D intensity has been stable since the mid-1960s, the composition of R&D spending has changed dramatically, as Government funding has declined and private sector funding has increased to fill the void (see Figure 2). 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. Government tends to fund higher-risk basic research that private investors are often reluctant to take on. Therefore, public R&D investment tends to produce higher value, high spillover (see

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*.

below) inventions over a longer period of time. Despite the decline in government R&D funding, the private sector has also invested less in basic research over time (e.g. Arora, Belenzon & Pataconi, 2018).

Figure 1: R&D as a Proportion of GDP in Selected Countries, 1981-2017



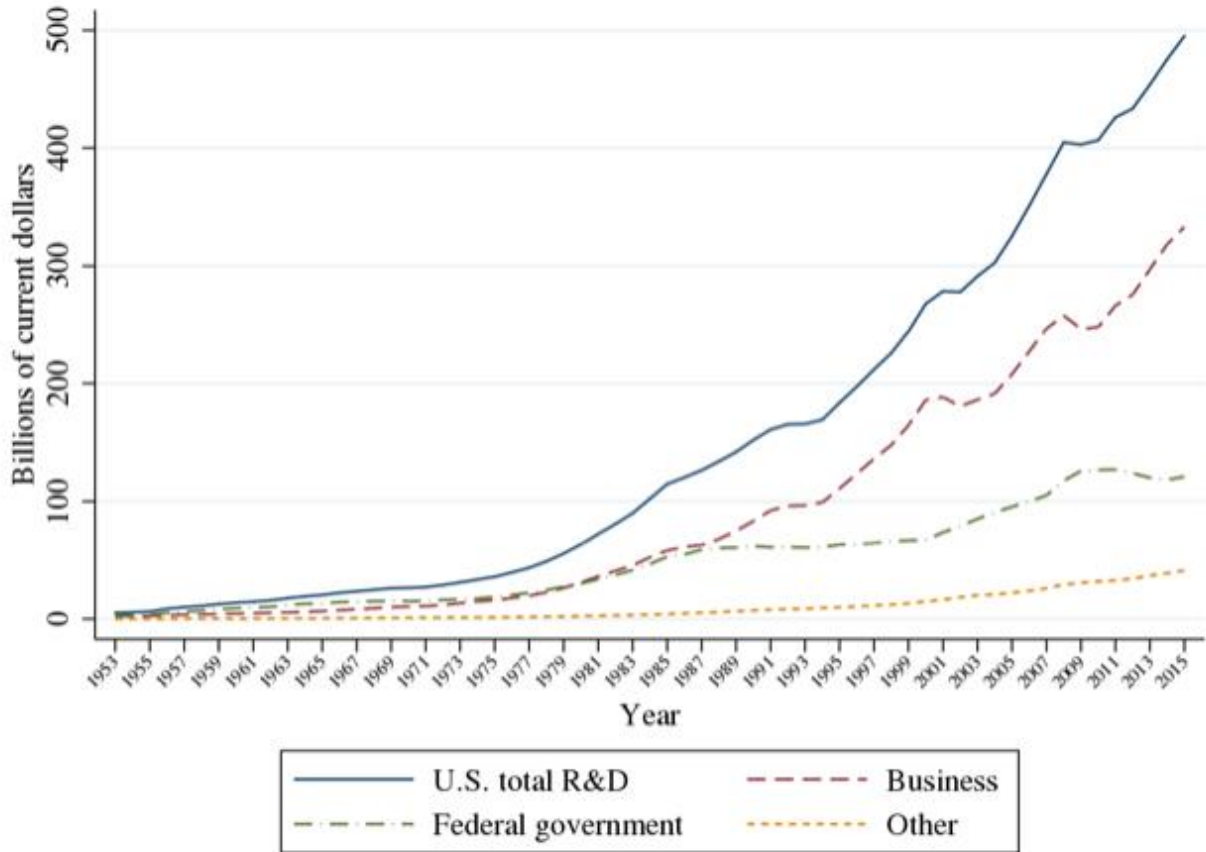
Source: OECD (2019).

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 US workers who are researchers grew consistently until about 2000, but has been stable between 0.7

and 0.9 percent over the last two decades. 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 the proportion of researchers from around 0.5 percent in 2000 to nearly 1.4 percent in 2015.

Figure 2: 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).

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), 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.

II. The Case for Government Promotion of 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.

III. Human Capital Innovation Policies

We now turn to consider explicit human capital policies.

III.1 Undergraduates and Postgraduates

The most commonly discussed policy here is to increase the number of individuals with training in science, technology, engineering and mathematics, commonly known as STEM. The direct way would be subsidizing PhDs and Postdocs in these subjects, increasing the generosity of support for training in these fields. Indirectly, training and subsequent careers in these fields could be made more attractive through more grants and support, especially in labs.

More generally, one can imagine support for raising educational attainment at an even younger age (undergraduates and even K12). There is a huge literature documenting the complementarity between human capital and new technologies (“skill biased technical change”), so increasing human capital could have a positive effect on technical change (e.g. Van Reenen, 2011; Autor, Goldin and Katz, 2020). However, this literature is usually focused on the diffusion of technologies (e.g. ICT adoption) rather than pushing forward the technological frontier. For

innovation to the economy (rather than to a firm), it is likely that Postgraduate qualifications are much more important.

There has been much macro-economic analysis of the impact of human capital on growth (for example, see Sianesi and Van Reenen, 2003, for a survey). However, the literature is rather inconclusive because of the difficulty of finding credible instruments at the macro (or industry) level. The large number of other confounders at the macro-economic level makes it hard to infer causality. There is a vast literature looking at the impact of schooling on wages, but there is rather a paucity of work looking at more specific interventions on the STEM (science, technology, engineering and mathematics) workforce.

III.2 University Expansion

There is a large literature examining the role of universities in economic prosperity in general and on innovation in particular. A major idea in these papers is that university founding and expansion increases the supply of workers with STEM qualifications and that these STEM workers increase innovation. 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).

Valero and Van Reenen (2019) find that the founding of a university increases local GDP per capita growth in subsequent years (that also spills over nationally) looking at 50 years of subnational data across over 100 countries. The Jaffe (1989) paper was a pioneer in this area by documenting that state-level spending on university research in certain industries seems to generate higher local corporate patenting. Acs et al (1992) use innovation counts instead of patent data and find even stronger effects for spillovers from university research. Related findings of the positive effects of university location on patenting has been found in more recent datasets by Belenzon and Schankerman (2013), Hausman (2018) and Andrews (2018). Furman and MacGarvie (2007) study how universities with stronger academic research profiles increase the growth of local industrial pharmaceutical labs 1927 to 1946. They use land grant college funds under the Morrill Acts to generate some exogenous variation in the location of universities to argue that the correlation is causal. In the biotech industry, Zucker et al (1998) show that firms tend to locate near universities to take advantage of star scientists.

However, universities may also have other effects on innovation over and above the supply of graduates. Firstly, research and innovation by university faculty, possibly collaborating with private sector firms could also directly increase innovation. The vast literature on clustering has this as one of the mechanisms. Secondly, universities may influence local democratic participation and institutions, which may also have an effect on innovation. If universities have an effect on innovation (or growth) over and above the impact on human capital, then they are not valid instruments for human capital, as this violates the exclusion restriction. For example, Valero and Van Reenen (2019) found that university expansion was associated with more graduates, more innovation and stronger institutions. Of course, the reduced form effect of universities on innovation is still an interesting effect if it is causal, but the mechanism through which universities raise innovation may not be solely (or even at all) through the human capital channel.

Graduate supply

To make progress in isolating why universities may have an impact on innovation as key suppliers of STEM workers, Toivanen and Väänänen (2016) document that individuals growing up around a technical university (such institutions rapidly expanded in the 1960s and 1970s in Finland and offered postgraduate engineering) were more likely to become engineers. They showed that this led to significantly greater patent activity. Establishing three technical universities caused on average a 20% increase in USPTO patents by Finnish inventors. In a similar vein, Carneiro, Liu and Salvanes (2018) compare municipalities in Norway where there was an upsurge in government college start-ups in the 1970s to synthetic cohorts of areas where the expansion did not take place. They document evidence for more R&D and a speed up in the rate and direction of technological progress about a decade after the colleges' founding (if they were STEM-focused).

Bianchi and Giorcelli (2019) present the most direct test of the role of universities increasing STEM supply. They exploit a change in the enrollment requirements for Italian STEM majors, which has a major effect of expanding 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.

Research Grants to Academics (and beyond)

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). Spending public R&D subsidies on universities makes sense as spillovers from basic academic research are likely to be much larger than those from near-market applied research.

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 (as discussed above). 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 about a 4 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.

National Labs

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. Jaffe and Lerner (1990) analyze national labs, which are often managed by universities, and document evidence of spillovers. The UK's Synchrotron Diamond Light Source appeared to do create spillovers (Helmets 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.

Academic Incentives

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 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.

III.3 Immigration

Migration offers an alternative lens into the effects of human capital on innovation. Historically, the US has had a relatively open immigration policy compared to other developed countries that helped to make the nation a magnet for talent. Immigrants account for about 14% of the US workforce, but make up 17%-18% of college graduates and 52% of STEM doctorates. They also account for about a quarter of all patents and a third of all US Nobel Prizes.

Kerr and Kerr (This Volume) goes into more detail on immigration and innovation and surveys policy options around migration. Broadly, 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. 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.

There is some work pushing back against this generally positive view of the impact of immigration on innovation. Using H1-B visa lotteries, Doran, Gelber and Isen (2015) estimate smaller effects than Kerr and Lincoln (2010). In addition, Borjas and Doran (2015) actually argue for negative effects on academic publications by Americans in mathematics journals following the fall of the Soviet Union. They do not attempt, however, attempt to estimate aggregate effects and 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. In addition, Moser, Voena, and Waldinger (2014) estimate that most of the effect of immigration on innovation comes from new entry, rather than incumbents.

In summary, my reading of the literature is that there is good evidence that immigration, especially skilled immigration raises innovation. It is a particularly attractive policy because the cost of educating immigrants has been born by other countries rather than American taxpayer subsidies and, unlike many other supply side policies, the increase in human capital can occur very quickly. However, there are severe political problems with relaxing immigration policy (see Tabellini, 2019).

III.4 Increasing the quality of inventors: Lost Einsteins

New Facts on Inventor backgrounds

There has long been interest in the background of inventors, with statistical analysis of this beginning with Schmookler's (1957) study. More recent work has documented many features of inventors in near population studies. Bell et al (2019a) measure inventors by those individuals who are named as inventors on the patent document (both applied and granted patents), not those who are granted the intellectual property rights (typically the assignee will be the company that the inventors work for, rather than the individuals themselves). Looking at about 1.2 million inventors since the mid-1990s, they find that many groups are highly under-represented in the inventor such as women, minorities and those born into low-income families.

Using the inventor data matched to de-identified US IRS data, Bell et al (2019a, b) are able to follow potential inventors across their lifecycle. Figure 3 shows the fraction of kids who grow up to be inventors by the percentile of their parents' income. There is a strong upwards sloping relationship showing that being born to wealthier parents dramatically increases the likelihood of becoming an inventor. For example, 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. This is not due to wealthier children producing simply low value innovations – conditioning on the top 5% of the most highly cited patents produces near identical results.

An obvious explanation for the dramatic differences in Figure 3 could be that kids in poorer families have worse innate abilities than their richer counterparts. For example, if wealthier parents are smarter, their kids are likely to be smarter and since intelligence and inventiveness are correlated, this could explain the patterns. To examine this Bell et al (2019a) match in math (and English) test score results from Third Grade and later, which are available for a subsample of the data. There is indeed a strong correlation between Third Grade math scores² and the probability of becoming an inventor in later life. However, these early test scores account for only under a third of the innovation gap: the vast majority of the innovation-parental income

² We do not observe math grades before Third Grade, but it is likely that these partly reflect nurture rather than nature. As the work by Heckman and others have shown, early childhood experience has effects on cognitive and noncognitive outcomes at very young ages.

relationship remains unaccounted for.³ Figure 4 illustrates this by separating the inventor-ability gradient by whether a child was born in the top quintile of the parent income distribution or bottom four quintiles. For both “rich” and “poor” children the probability of growing up to be an inventor rises with math ability and is especially strong for kids in the top 10% of the test score distribution. However, even for kids who are in the top 5% of talent for math, Figure 4 shows that those from richer families are far more likely to become inventors.

Interestingly, later test scores become more informative: 8th grade math test scores account for just under half of the inventor-parental income gradient. By the time we know which college young people attended (e.g. MIT or Stanford), the role of parental income is tiny. Of course, being born to a poor family means that the chances of going to a top college are very, very low. This suggests that an important part of the transmission mechanism between parental income and later outcomes is through the quality of schooling – something we return to below when discussing policy.

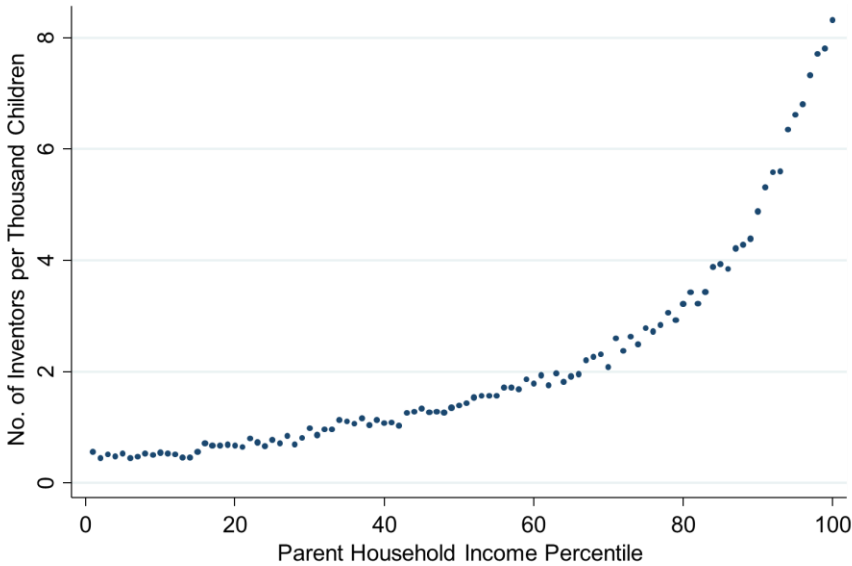
A similar story holds for gender and race (see also Cook and Kongcharoen, 2010). About 18% of inventors born in 1980 were female, up from 7% in the 1940 cohort. At this rate of improvement, it would take another 118 years to achieve gender parity. Looking at the New York City data there is essentially no difference in the Third Grade math ability distribution for boys and girls (even in the right tail). 1.6 per 1,000 white children who attended NYC public schools become inventors compared to 0.5 per 1,000 black children. Early ability accounts for only 10% of these differences.

An alternative explanation for the patterns in Figure 3 than ability differences, is that they relate to misallocation of talent. There has been a flourishing of work in recent years suggesting that large amounts of productivity are lost due to such frictions (e.g. Hsieh and Klenow, 2009; Hsieh et al, 2019; Celik, 2019). Under this view, if disadvantaged groups were given the same opportunities as their similarly talented, but more privileged peers, many more of them could have pursued an inventor career and increased the quality and quantity of aggregate human

³ For example, we can statistically “give” the distribution of math test scores of rich kids to poor kids using the DiNardo, Fortin and Lemieux (1996) re-weighting technique.

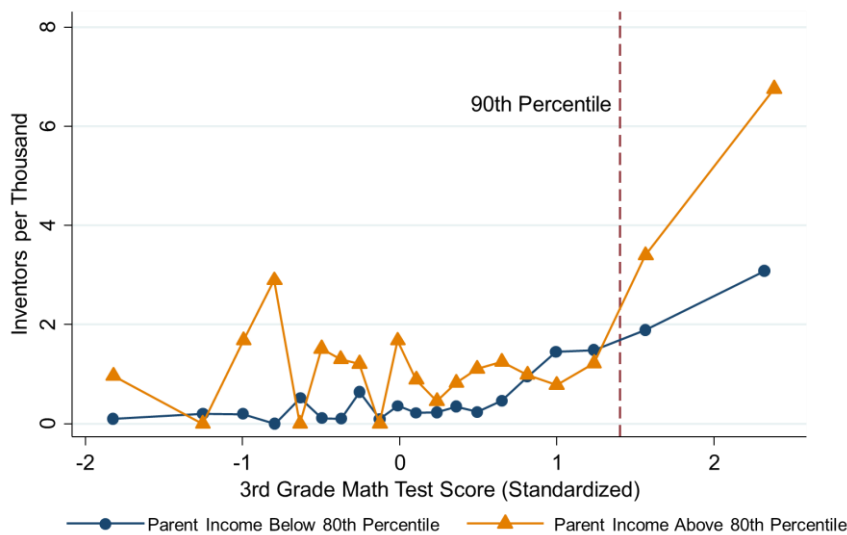
capital. For example, Bell et al (2019b) estimate a potential quadrupling of aggregate US innovation from reducing such barriers.

Figure 3: Probability of growing up to be an inventor as a function of parental income



Notes: Sample of children is 1980-84 birth cohorts. Parent Income is mean household income from 1996-2000. **Source:** Bell et al (2019a); Intergenerational sample

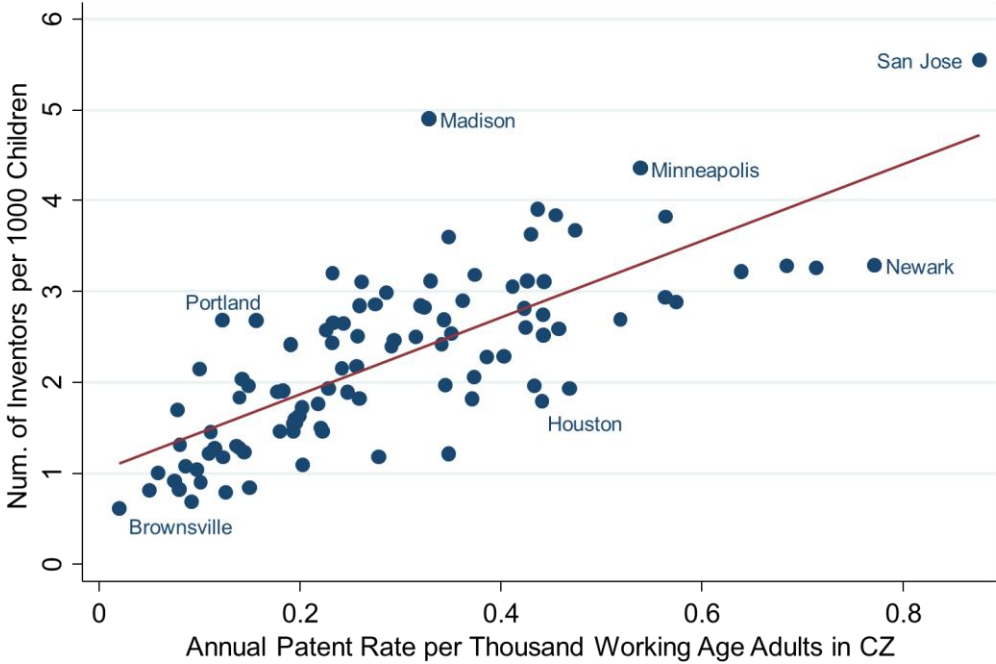
Figure 4: Relationship between math test scores and Probability of becoming an inventor



Source: Bell et al (2019a); New York City sample.

Bell et al (2019a) document that an important cause of the lower invention rate of disadvantaged groups appears to be differential exposure rates to inventors in childhood. They measure exposure by family environment, proxies for the work network of parents and innovation rates in the Commuting Zones where kids grew up. They find a strong association between the probability of growing up to be an inventor and measures of childhood exposure to inventors. Figure 5, for example, shows that children growing up in a Commuting Zone with a high density of inventors are much more likely to become inventors as adults. About 5.5 kids in every 1,000 in the San Jose commuting Zone (which encompasses Silicon Valley) become inventors, compared to about 1 in 1,000 in Brownsville.

Figure 5: Growing up in a high innovation area, makes it much more likely you will become an inventor as an adult



Source: Bell et al (2019a). 100 most populous Commuting Zones

The relationship between place and outcomes appears to be causal. For example, it is not simply the fact that kids who grow up in Silicon Valley are more likely to be inventors, they are more

likely to invent in the detailed technology classes (relative to other classes) that the Valley specializes in (say software compared to medical devices). Girls who grow up in places where there are a disproportionate fraction of women compared to male inventors are more likely (than boys) are to grow up to become inventors. Furthermore, kids who move to high innovation areas at an earlier age are more likely to become inventors than kids who moved at a later age, again suggesting a causal impact of place.

This “exposure based” view of invention, could lead to much larger welfare losses than in the standard talent misallocation models. In Hsieh et al (2019) for example, barriers to entry into occupations (the R&D sector in this case) means a loss of talent. However, since their model is a fully rational Roy sorting model, only the marginal inventors are discouraged from becoming inventors. Great inventors – like Einstein or Marie Curie – will never be put off. In the exposure based model, however, even very talented people from (say) a poor family may end up not becoming an inventor, because they are never exposed to the possibility. Bell et al (2019a) show evidence in favor of this and argue for large first-order welfare losses.

Some Policies towards the Lost Einsteins

If we took seriously the idea that much talent is being lost because of a lack of exposure to the possibility of becoming an inventor, what are the appropriate policy responses?

A classic set of responses would focus on improving conditions in disadvantaged neighborhoods particularly in schools. These are justified on their own terms, but the misallocation losses add to the usual equity arguments. It would make sense to target resources on these most likely to benefit: disadvantaged kids who show some early promise. Figure 4 showed that being in the top 5% of third grade math scores were strong predictors of future inventor status. This suggests looking programs that identify early high achievers from under-represented minorities.

One example is Card and Giuliano (2016) who look at the effect of in-school tracking for minorities. They look at one of the largest US school districts where schools with at least one gifted fourth (or fifth) grader had to create a separate “gifted/high achiever” (GHA) classroom. Since most schools only had a handful of gifted kids per grade, most seats in the GHA classroom

were filled with non-gifted students who were high achievers in the same school-grade. They served as upper track classes for students based on past achievement. Moreover, since schools were highly segregated by race and income, the program effectively treated a large number of minority students, who would typically not be eligible for standard “gifted and talented” interventions.

The authors use a Regression Discontinuity Design to examine the causal effects on students who are tracked since selection is based on a continuous measure of past achievement with a threshold. They found that students significantly improve their math, reading, and science when assigned to a GHA classroom, but these benefits were overwhelmingly concentrated among Black and Hispanic participants. Minorities gained about 0.5 standard deviation units in math and reading scores which persisted until at least the sixth grade. These are very substantial gains, comparable in magnitude to “high performance” charter schools evaluated by Angrist et al (2013). A concern is that the gains of the participating minorities was at the expense of those who were left behind. To address this, the paper uses a cohort difference-in-differences design comparing schools who tracked vs. those who did not. They find no evidence of negative (or positive) spillovers from this analysis. The effects do not appear to be coming from teacher quality or peer quality. Rather, the authors suggest that teacher expectations may play a very important role in exposing students to the possibility of greater learning.

Changing to in-school tracking has little financial cost, as there is not an expansion of the number of teachers, classes or school day. This in-school tracking is a reallocation of existing resources. This suggests that such interventions could have very large benefits in terms of growth as well as equity.

Card and Giuliano (2016) look at the short term outcomes of within school tracking. By contrast, Cohodes (2020) examines the long-term effects of a similar program in Boston Public Schools’ Advanced Work Class (AWC) program. Pupils who do well on third grade test scores are placed in the AWC program and receive a dedicated classroom with high-achieving peers, advanced literacy curricula, and accelerated math in later grades. While the students who participate in

AWC tend to be more advantaged than Boston Public School students as a whole, about half of AWC students are Black or Latino, and two-thirds of them receive subsidized school lunch.

The paper estimates the effect of the program using a fuzzy regression discontinuity comparing those who scored just above and just below the admissions threshold. There is a large increase in high school graduation for minority students. Perhaps most importantly, AWC boosts college enrollment rates. The program increases college enrollment by 15 percentage points overall, again with gains primarily coming from Black and Latino students. This results in a 65 percent increase of college enrollment for Black and Latino students, most of it at four-year institutions. Using estimated earnings associated with colleges from Chetty et al. (2017) as a measure of college quality, AWC appears to increase in college quality by about \$1,750 for all students and \$8,200 for Black and Latino students, though these differences are not statistically significant.⁴

Bui, Craig, and Imberman (2014) is sometimes seen as a counter-example as their RDD analysis of a Gifted and Talented program found no effect. However, the paper does find an effect on science outcome, which may be the critical element for inventors. Furthermore, the paper does not look at heterogeneity of the treatment effect by income group or minority status.

Another set of targeted policies is around mentorship. The Lemelson Foundation, for example, runs “inventor education” programs targeting at disadvantaged children in Middle and High Schools. An important part of this is hands on experience of problem solving in the local community and meeting inventors who look like the targeted groups (e.g. women scientists for girls). More generally, one can imagine internship and work exchange programs, which are targeted at young people who would not normally be exposed to high innovation environments.

Gabriel, Ollard and Wilkinson (2018) have a useful survey of a wide range of “innovation exposure” policies focusing on school age programs. Although there are a large number of such

⁴ Although attending an AWC class boosts the average test scores of peers by over 80 percent of a standard deviation, Cohodes (2020) finds little evidence to support peer effects as an explanation for AWC impacts. While AWC teachers have higher value-added, the change is not large enough to account for the gains in college attendance observed here. Instead, it appears that AWC is the beginning of a chain of events that causes participants to stay on-track for college throughout high school.

programs (science competitions being a leading example), they tend to be dominated by students with higher income parents, boys and non-minorities. Moreover, the programs are almost never subject to evaluation. One immediate priority should be resources into researching their impact.

IV. Conclusions

Innovation is at the heart of growth and increasing the supply of potential inventors would seem the natural place to start to think about innovation policy. Yet the literature has tended to focus much more on policies that raise the demand for innovation by the tax system or direct government grants, than intervening on the supply side. At one level, this is surprising as if supply is inelastic; demand side policies may do little to the volume of innovation and may just increase the wages of R&D scientists. On another level, this is unsurprising: supply side policies will tend to work more in the long run that makes them harder to empirically evaluate.

In this paper, we have looked at several different human capital policies for innovation: increasing STEM, immigration reform, universities and exposure policies for the disadvantaged. Clean causal identification of policies is rarer here than in other areas, but there have been some recent and encouraging contributions. In the short run, liberalizing high skilled immigration is a low hanging fruit. In the longer run, we suggest exposure policies may have the greatest effect, but much more work needs to be done in evaluating the effectiveness of such policies.

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