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Innovation and Human Capital Policy

John Van Reenen

2.1 Introduction

Since the 1970s, productivity growth in the United States has slowed—reflected in falling total GDP growth from 4 percent in the postwar years, to under 3 percent from the mid-1970s, and to under 2 percent since 2000. Average real wage growth has also slowed over this period, especially for less educated workers. Moreover, at the time of writing, the COVID pandemic has damaged growth by more than any other shock in living memory.

For the most economically advanced countries like the United States, innovation is the critical ingredient to long-run productivity growth. For less developed countries, much productivity can come from catching up to leading nations through diffusion of technological know-how. Even in richer nations, many organizations are behind the technological frontier, and interventions such as upgrading management practices (e.g., Bloom and Van Reenen 2007), speeding up adoption, and reducing the misallocation of resources are extremely valuable. Nonetheless, innovation policy design is a key part of any solution for revitalizing America and can lead to large increases in well-being.

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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 research and development (R&D) grants can be effective in increasing firms' incentives to do more R&D—and there is an impressive body of microeconomic research on this (Akcigit and Stantcheva 2020; Bloom, Williams, and Van Reenen 2019). However, if the supply of R&D workers is very inelastic, then there is a risk 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 on innovation prices rather than innovation quantities. 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 standard 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.

In reality, the elasticity of supply of R&D workers is unlikely to be completely fixed, especially when we consider immigration into the United States (see below). However, in the short run, supply could be relatively hard to expand, so these concerns are real.

A supply side increase in the quantity and quality of R&D workers carries fewer of these risks. Unless the new workers are dramatically less productive than the existing stock or large quantities "leak out" out into noninnovative activities, we would expect a direct increase in innovation. Furthermore, the increase in the supply of R&D workers should reduce the equilibrium cost of R&D—meaning that a successful supply side policy provides a further indirect boost to the amount of innovation as firms face lower R&D costs. The work in this chapter focuses on such human capital supply side policies.

The structure of the chapter is as follows. I provide some background R&D and workforce statistics in section 2.2; in section 2.3, we discuss the rationale for (and evidence on) innovation subsidies; in section 2.4, we discuss the evidence for four types of human capital supply policies. Section 2.5 offers some concluding comments.

2.2 Background: R&D and the Scientific Workforce[1]

In 2015, spending on R&D performed in the United States was just under half a trillion dollars. Figure 2.1 shows R&D spending as a fraction of GDP for major industrialized countries. The United States spends more on R&D than any other, accounting for roughly 28 percent of global R&D spending.

1. Most of the data facts in this paper are drawn from National Science Board (2018).

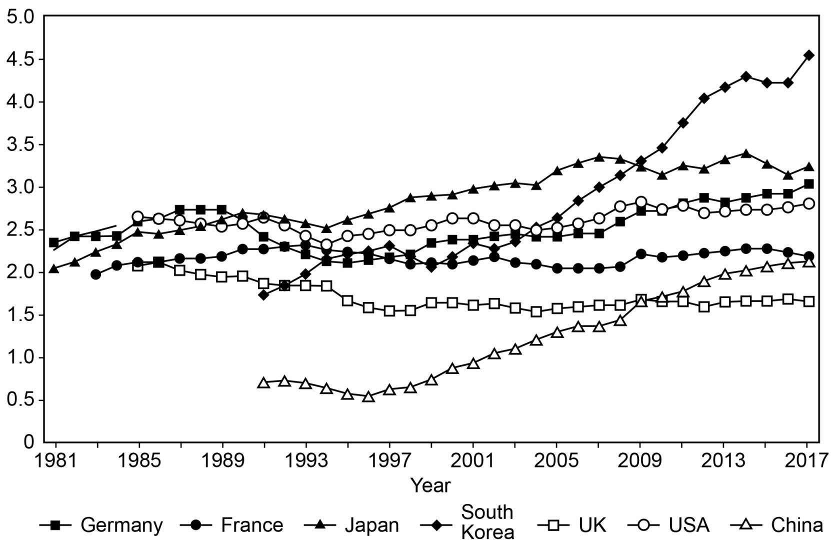

Fig. 2.1 R&D as a proportion of GDP in selected countries, 1981–2017
Source: OECD (2018).

It has maintained an R&D-to-GDP ratio of between 2.5 and 2.7 percent since 1981 (up from 1.3 percent in 1953).

Looking at the time series, however, the situation is less reassuring. China has clearly had a spectacular boom in R&D intensity, but most countries have also enjoyed an increase. Furthermore, the composition of US R&D expenditure has changed significantly: the fraction of government funding has declined precipitously and the share of private-sector funding has risen (see figure 2.2). This matters because the government often supports more basic and higher-risk research than the private sector. Consequently, public R&D will tend to produce the inventions that create the highest knowledge spillovers in the long run. Moreover, there is some evidence that even within private-sector-funded R&D, basic research has declined relative to applied research (e.g., Arora, Belenzon, and Patacconi 2018). The decline in basic research in both public- and private-sector R&D spending may be one reason why the productivity of American R&D appears to have fallen over time, as documented by Bloom et al. (2020).

Colleges and universities are particularly important for basic research (mostly funded by the federal government; they account for just under half of this total). 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.

These statistics focus on R&D spending, but perhaps more germane to

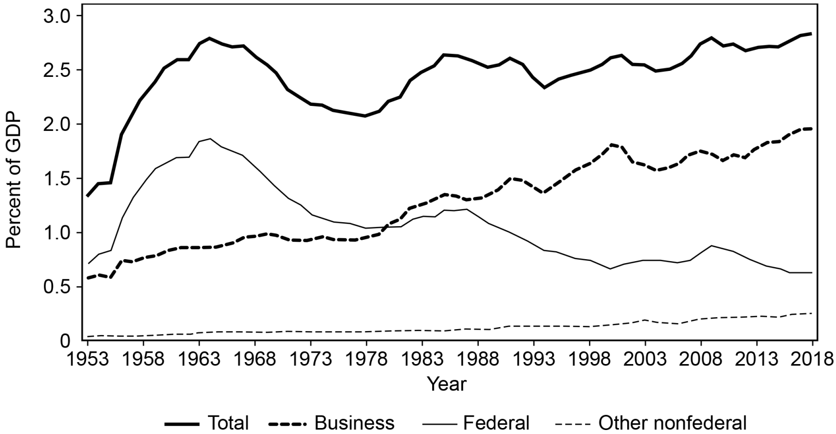

Fig. 2.2 US R&D, by source of funds, 1953–2015

Source: National Science Board (2018).

Notes: R&D spending is categorized by funder rather than performer. Other nonfederal funders include, but are not limited to, higher education, nonfederal government, and other nonprofit organizations.

Table 2.1 Number of researchers per 1,000 employees, selected countries

	United States	China	France	Germany	Korea	Japan	United Kingdom
1981	5.28		3.78	4.65		5.23	5.25
2001	7.29	1.02	6.83	6.63	6.32	9.87	6.57
2018	9.23	2.41	10.9	9.67	15.33	9.88	9.43

Source: OECD, Main Science and Technology Indicators, https://stats.oecd.org/Index.aspx?DataSetCode=MSTI_PUB#downloaded11.21.20.

Note: US figure is for 2017, as 2018 was not yet published at time of writing.

our focus on innovative human capital is the scientific workforce. Table 2.1 shows that the fraction of all US workers who are researchers has grown consistently since 1981, just like the R&D to GDP ratio. There were about 5.3 researchers per thousand workers in 1981, 7.3 in 2001, and 9.2 in 2017. However, the growth was faster in other advanced economies. France, Germany, and Japan all had lower numbers in 1981, but have overtaken the United States in the most recent years. The most dramatic change over that period has been in South Korea, where the ratio of researchers per thousand employees rose from 6.3 in 2001 to 15.3 today. China's fraction of researchers looks less impressive than its R&D spending in figure 2.1, but it has still more than doubled the researcher proportion since 2001 from 1.0 to 2.4.

Another way of approaching the measurement of science workers is to look at high-skilled visas: J-1 (exchange visitors), H-1B, and L-1 (intracompany transferee). There was an increase from around 150,000 to over 330,000 between 1991 and 2015 for J-1s, the largest category. There was an increase of 52,000 over this same time period in H-1B visas to 175,000. This growth was focused in nonprofit research facilities, universities, and government research labs.

2.3 The Case for Government Promotion of Innovation

Jones and Summers (2021) examine the arguments on why government should support R&D, so we briefly summarize the arguments here (see Bloom, Williams, and Van Reenen 2019 for more detail). In short, theory and evidence imply there are too few innovation workers in America.

The main theoretical argument for government intervention is that there are externalities from R&D as knowledge has characteristics of a public good. The agents who invest their time and resources in innovation expect to see some return, even if it is uncertain. However, many other parts of society will benefit without having to pay much, if any, of this R&D cost. These include firms who imitate the innovation or build on the knowledge created by the inventor's R&D efforts. There are also the consumers (at home and abroad) who enjoy the benefits of the innovation but whose purchase price may be only a tiny fraction of the cost. Indeed, in his *Dictionary of Received Ideas*, Gustave Flaubert (1911) ruefully defined inventors as follows: "All die in the poor house. Someone else profits from their discoveries, it is not fair."

Since the firms and workers engaging in R&D do not capture all of the value of the innovations produced, there will tend to be underinvestment. In other words, the social benefits of R&D will be higher than the private investment in a decentralized market economy. Consequently, there needs to be some government action to promote innovation and bring social and private returns more into line with each other.

There are likely to be many other market failures that mean the level of R&D is suboptimal. For example, Arrow (1962) emphasized financial market failures due to the risk, uncertainty, absence of collateral, and asymmetric information inherent in raising money for innovation (see Hall and Lerner 2010 for empirical evidence). Fundamentally, an inventor wanting to raise finance for her idea will have to convince an external investor of the idea's value. Since the only way to do this is to share more information on the idea, the inventor will be rightly concerned that the information will leak out and be stolen by someone else (such as the financier himself). Hence, R&D will tend to be internally financed within firms, and many good ideas may end up being unrealized.

Another market failure can be traced to product market rivalry. Once we leave the textbook model of perfect competition, an important incentive to innovate is that one firm gains nontrivial market share from another. This "business stealing" motive was germane to Schumpeter's notion of creative destruction and is at the heart of Industrial Organization models and endogenous growth theory, in particular Aghion and Howitt (1992). This means that firms may be in an R&D "arms race" and this can lead to duplicative effort and too much R&D. From a social point of view, a pure reshuffling of market shares is of little value if there is not much fall in quality-adjusted prices. An example would be in parts of the pharmaceutical industry where "me-too" drugs of minor therapeutic improvement can lead to large shifts in market share as doctors and patients want only the best drug (and because of insurance, there is often little sensitivity to price).

A further issue is that the policies that are designed to create incentives to innovate can themselves create other distortions. For example, the intellectual property system generates a temporary monopoly for inventors to overcome the knowledge spillover problem through patents. Of course, these property rights themselves create a consumer loss through higher prices. Further, many patents can be "designed around" and offer little protection. Perhaps most worryingly, the patent system can be abused to create many barriers in order to protect minor increments to knowledge, such as "patent thickets" (see Jaffe and Lerner 2007 for a general discussion).

Given all these complexities, whether the social benefits of R&D exceed the private returns cannot be answered by theory. It is an empirical question. One approach for answering the question is to use case studies. For example, there are many case studies of government interventions that were failures (Lerner 2005), such as the Anglo-French supersonic aircraft Concorde. On the other hand, there are also many examples of major successes, such as jet engines, radar, nuclear power, GPS, and the internet (Janeway 2012; Mazzucato 2013), that began with government funding (often around military spending, with civilian spin-offs an expected spillover benefit). Despite their richness, these historical examples can be hard to assess, although there have been some attempts at more quantitative case studies, beginning with Griliches's (1958) famous hybrid corn analysis. It is still an issue, as Griliches himself emphasized, that it is hard to generalize from case studies, as they are single technologies selected precisely because they appear interesting and successful.

The modern econometric literature on spillovers has tried to look over a wider range of technologies, firms, and industries. One important strand of the literature uses patent citations. The idea is that that a citation is a paper trail indicating that one idea has built upon another (Trajtenberg 1990; Jaffe, Trajtenberg, and Henderson 1993; Griffith, Lee, and Van Reenen 2011). As is well known, however, not all innovations are patented and not all patents are innovations. An alternative approach is to look at the impact of R&D on the productivity not only of the firm who performs the research but also of other firms ("neighbors") who have spillover benefits. The key issue is how to empirically determine who else benefits and who does not—this is a generic problem in social science when thinking about "peer effects" (Manski 1993).

Using panel data on US corporations from 1980 onward, Bloom, Schankerman, and Van Reenen (2013) suggest a methodology based on "distance metrics." The idea is to characterize pairs of firms as close or far apart in technological distance, for example, as proxied by the technological classes where the firms have taken out patents in the past (Jaffe 1986). A firm that is close to another technologically is more likely to benefit from its neighbor's R&D than one that is more distant. A symmetrical argument can be made for business stealing through R&D by characterizing the closeness of multiproduct firms in product market space depending on their sales across their product portfolios.[2] In this case, R&D by a neighboring firm close in product market space is more likely to cause harm. Empirically, the authors show that although both knowledge spillovers and business rivalry effects from R&D are significant, the knowledge spillover effects quantitatively dominate. Note that a strong correlation between changes in a firm's productivity and growth in its neighbors' R&D (even controlling for the firm's own R&D and other factors) is not necessarily causal. Other factors, such as a demand shock or an opening up of scientific opportunities, could drive up both the firm's own productivity and neighbors' R&D. To tackle this question, the authors use innovation policy changes as natural experiments, such as the differential exposure of firms to changes in state and federal R&D tax credits. These policy changes successfully shifted the incentives to perform R&D across firms, generating instrumental variables for the spillover terms and enabling the authors to identify the causal effects of R&D spillovers.

For the US economy as whole, Bloom, Schankerman, and Van Reenen (2013) find that social returns to R&D were about three times higher than private returns between 1980 and 2000. Lucking, Bloom, and Van Reenen (2020) confirm this conclusion using the same methodology, but on more recent data running through 2015.

The finding that on average social returns to R&D exceed private returns (primarily due to knowledge spillovers) even with the level of support the US government provides is the current empirical consensus.

2.4 Human Capital Innovation Policies

There are many possible policies to deal with the innovation deficit. We now turn to consider explicit human capital policies to deal with the problem.

2.4.1 Undergraduates and Postgraduates

The most commonly discussed policy here is to increase the inflow of individuals trained in STEM (science, technology, engineering, and math-

2. The distance-based methods can be extended in other dimensions such as geography. Different firms with inventors who are colocated, for example, might be more likely to benefit from each other's R&D activity (e.g., Lychagin et al. 2016).

ematics). The direct way would be to subsidize 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 K through12). 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., Autor, Goldin, and Katz 2020; Van Reenen 2011). However, this literature is usually focused on the diffusion of technologies (e.g., adoption of information and communications technology) rather than on 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.

Much macroeconomic analysis has been conducted of the impact of human capital on growth (see, e.g., 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 aggregate 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 workforce.

2.4.2 University Expansion

Many papers examine the role of universities in economic prosperity in general and in innovation in particular. A major idea in these papers is that the founding and subsequent expansion in universities increases the supply of workers with STEM qualifications, and that these STEM workers then increase innovation. Geographically, places with strong science-based universities also seem to have substantial private-sector innovation (e.g., Route 128 in Massachusetts or Silicon Valley in California).

Valero and Van Reenen (2019), looking at 50 years of subnational data across more than 100 countries, find that the founding of a university increases local GDP per-capita growth in subsequent years (which also spills over nationally). 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, Audretsch, and Feldman (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 (2020). Furman and MacGarvie (2007) studied how universities with stronger academic research profiles increased the growth of local industrial pharmaceutical labs from 1927 to 1946. They used 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, Brewer, and Darby (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. First, research by university faculty, sometimes in collaboration with local private-sector firms, could 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. 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 interesting 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.

2.4.2.1 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) find that people who grew up around a technical university in Finland had a higher probability of becoming engineers when they reached adulthood. These technical universities rapidly expanded in the 1960s and 1970s in and offered postgraduate engineering. This also led to more patenting: establishing three technical universities caused on average a 20 percent increase in US Patent and Trademark Office 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 in increasing STEM supply in Italy. The enrollment requirements for STEM majors changed, and this generated a big increase in graduate numbers. In turn, innovation then increased, especially in medicine, chemistry, and information technology. Notably, however, they document that many STEM graduates ended up working in areas such as finance, rather than in the R&D sector. This "leakage" problem is a general one in just increasing the supply side, rather than targeting R&D per se.

2.4.2.2 Research Grants to Academics (and Beyond)

One variety of government programs that seek to encourage innovation is through the direct provision of grant funding (e.g., through the National Institutes of Health, or NIH), either to academic researchers or more widely. Spending public R&D subsidies on universities is intuitive because knowledge spillovers from basic academic research will likely be greater than those from corporate near-market applied research.

The challenge with evaluating whether R&D grants work is that they will tend to target the most promising projects, researchers, and problems. Hence, there could have been positive outcomes even without the grant. Public grants could even crowd out private funding. More optimistically, the grants could also crowd in matched private money (funders certainly try to obtain such "additionality").

Administrative data on US NIH grant applications have been used by Jacob and Lefgren (2011). They implement a "Regression Discontinuity Design" (RDD) that compares applicants that just received a large grant to those that just missed out by using the evaluators' scores given to grant applicants. They find that the grants lead to an increase of about 7 percent (one additional publication over a five-year period). One explanation for the small effect is that those who "just lost" a grant often found alternative sources of funding.

Public R&D grants may affect private firms in several ways. First, academic work can spillover to private firms. Using variation in NIH funding across multiple research areas, Azoulay et al. (2019) find that on average there are an extra 2.7 additional patents filed by private companies following a $10 million increase in academic funding. Second, government-conducted R&D spending (e.g., in labs) can affect private firms. Military R&D spending, for example, is usually driven by exogenous political changes (e.g. Sputnik, the end of the Cold War and 9/11). Moretti, Steinwender, and Van Reenen (2019) use such changes in defense R&D spending and find that there was an elasticity of 0.4 between private and public R&D (i.e., a 4 percent increase in private R&D followed a 10 percent increase in publicly funded R&D). This implies that public R&D *crowds in* private R&D.

Third, government money can be directly given to private firms. Marginal winners and losers from the Department of Energy's Small Business Innovation Research (SBIR) grant applicants are compared by Howell (2017). She finds that early-stage (Phase I) SBIR grants double the chances a winner obtains future venture capital funding (a marker of commercializable innovation potential). They also increase patenting and sales. Howell et al. (2021) find that SBIR grants in the US Air Force also have positive effects on venture capital funding, technology transfer to the military, and patenting, using a Regression Discontinuity Design.

2.4.2.3 *National Labs*

Governments also fund their own R&D labs that may generate more research activity and jobs in the lab's specialist technological area and in its geographical location. Jaffe and Lerner (2001) analyze national labs, such as Stanford's SLAC (National Accelerator Laboratory) and document evidence of spillovers. Helmers and Overman (2017) also document spillovers from Britain's Synchrotron Diamond Light Source. However, this appeared to be primarily through relocation of activity within the UK rather than any aggregate nationwide increase.

2.4.2.4 *Academic Incentives*

How can policies be designed that allow university discoveries to be made in commercializable innovations? The 1980 Bayh-Dole Act changed the ownership of inventions developed with public R&D giving universities more ownership in the intellectual property. Many schools created "technology transfer offices" to support this process and Lach and Schankerman (2008) find that larger ownership of this intellectual property by scientists generated more innovation. Hvide and Jones (2018) look at Norway and find that when academics obtained full innovation rights, they became more likely to launch entrepreneurial start-ups and take out patents. Financial returns for academics seemed to get more ideas out of universities and turned into real products.

2.4.3 Immigration

An important mechanism for increasing human capital is through immigration. The United States historically has a more open immigration policy to other advanced nations. Immigrants account for about 14 percent of the US workforce but make up 17–18 percent of college graduates and 52 percent of STEM doctorates. They also account for about a quarter of all patents and a third of all US Nobel Prizes.

Kerr and Kerr (chapter 3 in this volume) go into more detail on immigration and innovation, and on survey policy options around migration. Much research has found that US immigrants (especially the more high skilled) increase innovation. For example, using state panel data from 1940 to 2000, Hunt and Gauthier-Loiselle (2010) find that increasing the share of immigrant college graduates by one percentage point boosts patenting per person by 9–18 percent. Using changes in policies over H-1B visas, Kerr and Lincoln (2010) find positive effects and argue that these come through the innovation efforts of immigrants themselves. When an inventor dies, this is an exogenous shock to team productivity. Bernstein et al. (2018) find large spillover effects of immigrants on native innovation from such changes (large spillovers are also found by Hunt and Gauthier-Loiselle 2010).

In the early 1920s, the American government introduced immigration quotas with differential degrees of strictness for different countries. Northern Europeans, like Swedes, were less strongly affected than southern Europeans, like Italians. This variation has been exploited to examine how immigration reductions affected innovation. Biographical data in Moser and San (2019) show that these quotas discouraged southern and eastern European scientists from migrating to America. This in turn, depressed US aggregate invention. Negative effects of the quotas are also found in Doran and Yoon (2018). In a similar vein, the arrival in the US in the 1930s of Jewish scientists expelled by the Nazis boosted innovation in American chemistry (Moser, Voena, and Waldinger 2014).

Some work pushes back against this generally positive view of the impact of immigration on innovation. Smaller effects are seen from H-1B visas by Doran, Gelber, and Isen (2015) than Kerr and Lincoln (2010) when lotteries are used to examine the impact. Indeed, Borjas and Doran (2012) argue that publications by US mathematicians actually fell following the fall of the Soviet Union. Their work does not estimate aggregate effects, however. In addition, Moser, Voena, and Waldinger (2014) estimate that most of the effect of immigration on innovation comes from new entry, rather than incumbents. It may also be that be that Borjas and Doran's (2012) findings reflect special features of academic publishing, in particular the sharp short-run constraints on the size of journals and departments.

In summary, my reading of the literature is that there is good evidence demonstrating that immigration, especially skilled immigration, raises innovation. The benefit-cost ratio is particularly high because the cost of educating immigrants has been borne by other countries rather than by 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 2020).

2.4.4 Increasing the Quality of Inventors: Lost Einsteins

2.4.4.1 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 datasets. Bell et al. (2019a) measure inventors by those individuals who are named as inventors on the patent document (both applied and granted patents), not just those who are granted the intellectual property rights (typically the assignees will be the companies that the inventors works for, rather than the individuals themselves). Looking at about 1.2 million inventors since the mid-1990s, they find that many groups are highly underrepresented, such as women, minorities, and those born into low-income families.

Using the inventor data matched to deidentified US IRS data, Bell et al.

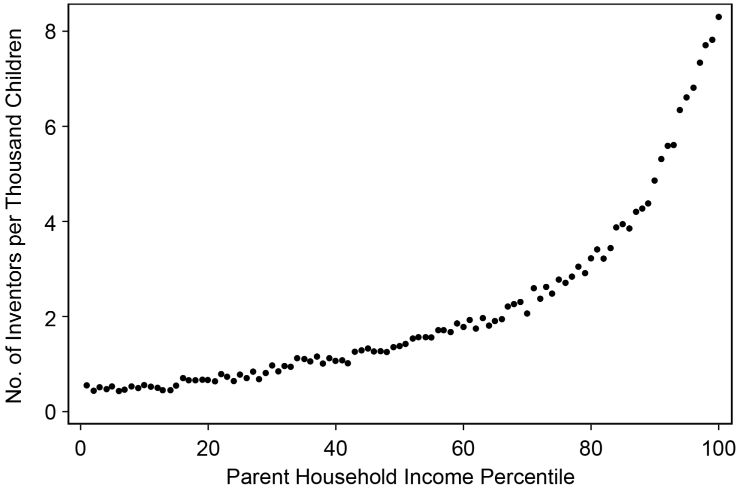

Fig. 2.3 Probability of growing up to be an inventor as a function of parental income

Source: Bell et al (2019a), p. 665; Intergenerational sample. Reprinted by permission of Oxford University Press on behalf of the President and Fellows of Harvard College.

Notes: Sample of children is 1980–1984 birth cohorts. Parent Income is mean household income 1996–2000.

(2019a, 2019b) are able to follow potential inventors across their life cycles. Figure 2.3 shows the fraction of children who grow up to be inventors by the percentile of their parents' income. There is a strong upward-sloping relationship, showing that being born to wealthier parents dramatically increases the likelihood of becoming an inventor later in life. Compared to kids born to parents in the bottom half of the income distribution, those born into the top 1 percent are an order of magnitude more likely to become inventors in the future. This is not due to wealthier children simply producing low-value innovations: conditioning on the top 5 percent of the most highly cited patents produces nearly identical results.

An obvious explanation for the dramatic differences in figure 2.3 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 hypothesis, Bell et al. (2019a) match 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 scores[3] and the probability of becoming an

3. Bell et al. (2019a, 2019b) cannot observe math scores before third grade, but it is likely that these partly reflect nurture rather than nature. As the work by Heckman and others has shown, early childhood experience has effects on cognitive and noncognitive outcomes at very young ages.

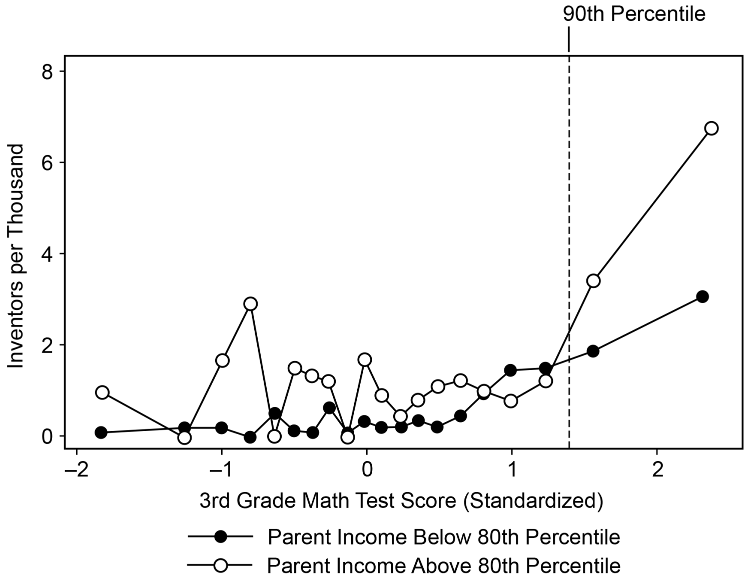

Fig. 2.4 Relationship between math test scores and probability of becoming an inventor

Source: Bell et al (2019a), p. 672; New York City sample. Reprinted by permission of Oxford University Press on behalf of the President and Fellows of Harvard College.

inventor in later life. However, these early test scores account for only under a third of the innovation gap; they cannot account for the vast majority of the innovation-parental income relationship.[4] Figure 2.4 illustrates this by separating the inventor-ability gradient by whether a child was born in the top quintile of the parental 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 percent of the test score distribution. However, even for kids who are in the top 5 percent of talent for math, figure 2.4 shows that those from richer families are far more likely to become inventors.

Interestingly, later test scores become more informative for inventor status: eighth 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

4. 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) reweighting technique.

is through the quality of schooling—something we return to below when discussing policy.

A similar story holds for gender and race (e.g., Cook and Kongcharoen 2010). About 18 percent of inventors born in 1980 were female, up from 7 percent 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). With regard to race, 1.6 per 1,000 white children who attended New York City public schools become inventors compared to 0.5 per 1,000 Black children. Early ability accounts for only a tenth of these differences.[5]

Rather than ability differences, an alternative explanation for the patterns in figure 2.3 is that it reflects a 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., Celik 2018; Hsieh and Klenow 2009). Hsieh et al. (2019), for example, estimate that 40 percent of the growth in US GDP per person between 1960 and 2010 is due to reductions in discrimination against women and Black people. 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 capital. For example, Bell et al. (2019b) estimate a potential quadrupling of aggregate US innovation from reducing such barriers.

Bell et al. (2019a) document that differential exposure rates to inventors in childhood is a very important cause of the lower invention rate of disadvantaged groups. 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 2.5, 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 children in 1,000 in the San Jose, California, commuting zone (which encompasses Silicon Valley) become inventors, compared to about 1 in 1,000 in Brownsville, Texas.

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 is a disproportionate fraction of female compared to male inventors are more likely (than boys are) to grow up to become inventors. Further-

5. Cook (2014) shows that racist violence between 1870 and 1940 led to 1,100 "missing patents," compared to 726 actual patents among African American inventors.

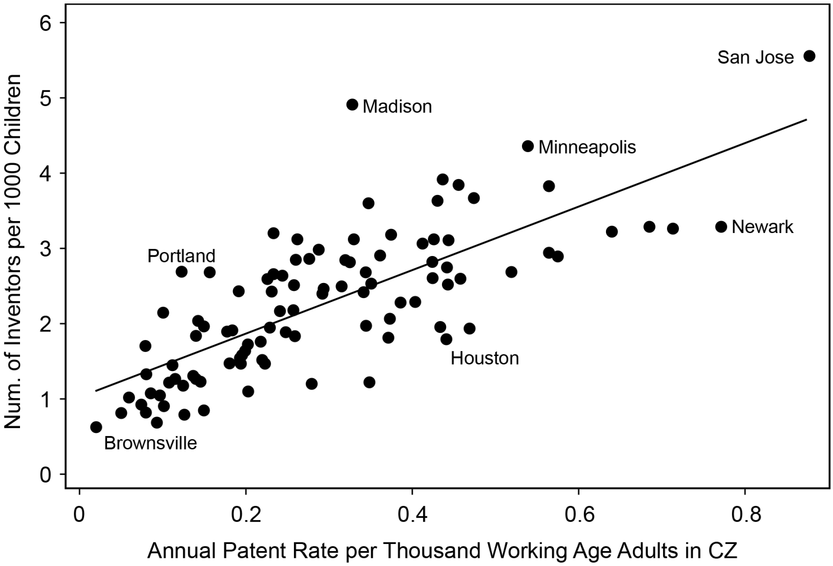

Fig. 2.5 Growing up in a high-innovation area makes it much more likely you will become an inventor as an adult

Source: Bell et al (2019a), p. 691; 100 most populous commuting zones. Reprinted by permission of Oxford University Press on behalf of the President and Fellows of Harvard College.

more, kids who move to high-innovation areas at an earlier age are more likely to become inventors than kids who move 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 our case) mean 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 inventors because they are never exposed to the possibility. Bell et al. (2019b) show evidence in favor of this and argue for large welfare losses.

2.4.4.2 Some Policies toward 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 those most likely to benefit, such as disadvantaged kids who show some early promise in STEM. Figure 2.4 shows that being in the top 5 percent of third grade math scores was a strong predictor of future inventor status. This suggests looking into programs that identify early high achievers from underrepresented minorities.

One example is Card and Giuliano (2016), who review 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/high achiever" (GHA) fourth- (or fifth-) grader had to create a separate GHA classroom. Since most schools only had a handful of gifted kids per grade, most seats in the GHA classroom were filled with nongifted 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 already in effect 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.

Card and Giuliano (2016) 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 find that students significantly improved 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, a result that persisted until at least the sixth grade (where their data end). These are very substantial gains, comparable in magnitude to "high performance" charter schools evaluated by Angrist, Pathak, and Walters (2013). A concern is that the gains of the participating minorities were at the expense of those who were left behind. To address this, the paper uses a cohort difference-in-differences design comparing schools that tracked to those that 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. The in-school tracking results from a reallocation of existing resources. This suggests that such interventions could yield 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.

Cohodes (2020) estimates the effect of the program using a fuzzy regression discontinuity design by 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 in 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 college quality by about $1,750 for all students and $8,200 for Black and Latino students, though these differences are not statistically significant.[6]

Bui, Craig, and Imberman (2014) is often seen as a counterexample, as their 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 parental income or minority status.

Another set of targeted policies is around mentorship. Many nonprofit foundations (e.g., the Lemelson Foundation and the Conrad Foundation) run "inventor education" programs targeting disadvantaged children in middle and high schools. Important parts of the program are 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 aimed at young people who would not normally be exposed to high-innovation environments.

Gabriel, Ollard, and Wilkinson (2018) have developed a useful survey of a wide range of "innovation exposure" policies focusing on school-age programs. Although there is a large number of such programs (science competitions being a leading example), they tend to be dominated by students with higher-income parents, boys, and nonminorities. Moreover, the programs

6. 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 a 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.

are almost never subject to evaluation. One immediate priority should be devoting resources to researching their impact.

2.5 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 through the tax system or through direct government grants, rather than policies that intervene on the supply side. At one level, this is surprising: if supply is inelastic, then demand side policies may do little to the volume of innovation and may merely increase the wages of R&D scientists. On another level, it is unsurprising: supply side policies will tend to work better in the long run, which makes them harder to empirically evaluate.

In this chapter, we have looked at several different human capital policies for innovation: increasing STEM, immigration reform, university expansion, 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 likely to yield a high return. In the longer run, I suggest that exposure policies may produce the greatest effect, but much more work needs to be done in evaluating the effectiveness of such policies.

When considering which policies to adopt, it is important to look carefully at the existing evidence and evaluate its strengths and weaknesses, as I have tried to do in this chapter. However, policy makers will frequently consider many other things rather than just a policy's cost-benefit ratio and how long it takes to see results. First, there is usually a close eye on the *distribution* of the benefits across people and places. "Lost Einstein" policies score well in this respect, as they both improve aggregate innovation and reduce inequality of opportunity. Gruber and Johnson (2019) have emphasized the need to spread innovation subsidies (such as new technology hubs) more widely in the US to embrace "left behind" geographical areas that have the capability to benefit due to existing education and are much cheaper than the high-cost clusters on the coasts. Secondly, rather than the usual economist practice of evaluating one policy at a time, we should consider the multiple interactions between innovation policies. Incorporating these in a growth plan involves building a portfolio of policies to address the most important missions facing Americans, particularly climate change, but also the challenges of improving health and security. Such a plan for growth (e.g., Van Reenen 2020) is likely to be more politically sustainable than a piecemeal approach and in the long run may produce greater gains in human well-being.

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