ANNUAL REVIEWS

Annual Review of Financial Economics

Government Intervention in Innovation

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Annu. Rev. Financ. Econ. 2024. 16:367–90

First published as a Review in Advance on June 17, 2024

The *Annual Review of Financial Economics* is online at financial.annualreviews.org

https://doi.org/10.1146/annurev-financial-082123-105722

JEL codes: O3, L26, G24

Keywords

innovation, policy, entrepreneurship, technology, R&D, entrepreneurial finance

Abstract

Governments' powerful imperative to support innovation has only grown more urgent amid slowing growth in the developed world and a rapidly changing climate. In this review, I describe the important role that economics and finance play in rigorously evaluating innovation policy. I organize government intervention in innovation into arenas, agendas, and instruments. The arenas are firms, financial intermediaries, universities, and government laboratories. The key agendas are entrepreneurship, defense, climate, health, and education. The instruments fall into three categories: supply-push, demand-pull, and legal. I provide theoretical rationales for government intervention in innovation and discuss how they intersect with government agendas and empirical evidence in practice. One takeaway is that the government has a key role to play in the type of failure-tolerant, open-ended research that yields breakthrough inventions. In contrast, there is less evidence that subsidizing financial intermediaries is useful.

1. INTRODUCTION

Governments almost universally encourage innovation, for innovation is the source of economic growth and national security. Amid slowing growth in the developed world and a rapidly changing climate, the imperative to support innovation has only become more urgent. The tools of economics and finance, designed to theoretically predict causal relationships and then test them rigorously in settings without randomized experiments, are well-positioned to evaluate innovation policies and guide governments in pursuing the most impactful and efficient programs.

Governments intervene in many ways; some programs share risk or cost directly (for example, by guaranteeing debt or offering grants), while others increase productivity by investing in human capital and physical infrastructure. I organize government intervention in innovation into arenas, agendas, and instruments. The arenas are firms, financial intermediaries, universities, and government laboratories. The key agendas are entrepreneurship, defense, climate, health, and education. The instruments fall into three categories: supply-push, demand-pull, and legal. Supply-push instruments affect production decisions. They include subsidies and tax benefits for innovation investment as well as direct public provision. Demand-pull instruments concern consumption; they include procurement, prizes, and price measures like pollution taxes. Legal instruments include intellectual property protection, antitrust, bankruptcy, and noncompete laws.

Innovation has a life cycle. It begins with an initial invention grounded in basic research that searches for new knowledge without a practical application in mind. The next step is to innovate a use for the idea, developing and demonstrating a technology. Finally, there is diffusion, by which the new product is commercialized or otherwise deployed. Across the continuum from basic to applied research and development (R&D)—as new technology moves from the invention to the diffusion stage—the instruments broadly shift from supply-push to demand-pull, and the sources of funding shift from government and university to the private sector.

In this review, I first provide rationales for government intervention in innovation and discuss how they intersect with government agendas in practice (Section 2). I then introduce the four arenas and, in the context of each, discuss the relevant instruments (Section 3). Academic research has focused primarily on evaluating specific instruments, usually one instrument per paper. There may be an acute "desk drawer" problem, where null results go unreported because they are difficult to publish. Yet governments pay attention to research in this area and can glean useful guidance from null effects. In this review, I will pay particular attention to program evaluations with null effects. The final section of the paper provides direction for future research.

Governments intervene in innovation in remarkably consistent ways around the world, often building off of examples set in the United States in the post–World War II period. For this reason, I focus most of my attention on the United States. More generally, I cannot exhaustively cover the large body of excellent academic literature in this brief review. Other reviews covering innovation policy include those by Gok et al. (2016) and Bloom, Van Reenen & Williams (2019).

Society's need for innovation, both radical and incremental, has never been more urgent. We face slowdowns in productivity growth and the rate of invention (Bloom et al. 2020), a decline in the role of entrepreneurial young firms in the economy (Decker et al. 2017), and potentially catastrophic climate change (Kemp et al. 2022). At the same time, the US government is playing a smaller role in innovation today than in the past. **Figure 1** below shows that the share of R&D spending in the United States from government sources has declined since the 1960s. Maximizing the benefits of government intervention in innovation requires high-quality, policy-oriented research on which instruments work and why. One takeaway from this review is to urge the field to value its important role in rigorous program evaluation.

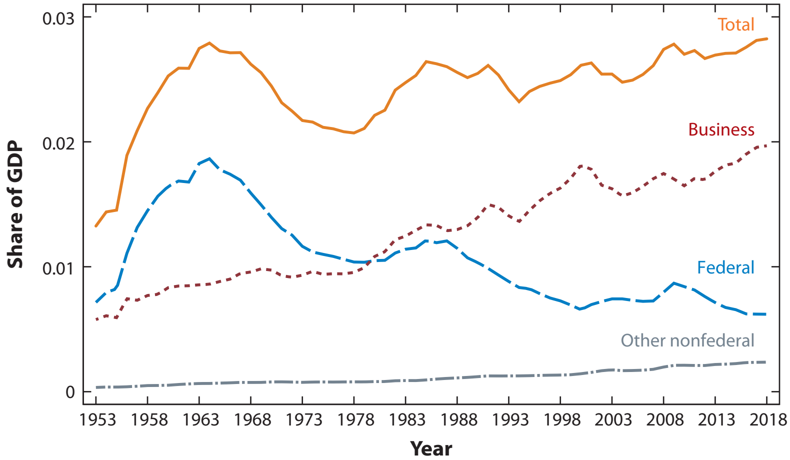

Figure 1

Fraction of total US research and development spending by source of funds. Data are for all years available from the National Science Board and the National Science Foundation Higher Education Research and Development (HERD) Survey. Figure adapted from Babina et al. (2023).

2. RATIONALES AND AGENDAS

From a theoretical perspective, why should governments intervene in innovation? And what are the reasons why, in practice, governments do intervene? In this section, I show how theory tends to identify market failures, while practitioners tend to identify positive agendas such as defense. While targeted sectors typically do face market failures, the diverging approach between economists and practitioners leads to important differences in outcomes via instrument choices.

2.1. Economic Rationales

There are broadly two major sources of market failures that offer sound motivation for government intervention in innovation: positive externalities and financial frictions. In this section, I address each in turn and then describe how they map to specific policy agendas. Last, I discuss the challenge of avoiding projects where government support will crowd out private investment.

2.1.1. Knowledge spillovers. The broadest positive externality is knowledge spillovers. We care about knowledge spillovers because new ideas are the basis of growth (Romer 1990, Jones 1995). Consider the lasers used for producing advanced semiconductors (i.e., computer chips), among many other applications. Lasers are possible because of a long history of science in thermodynamics, beginning with Max Planck's and Albert Einstein's basic explorations of radiation in the early 1900s. Starting in the 1950s, government-funded university researchers from Moscow to Boston built the first lasers. US national laboratories like the Lawrence Livermore National Laboratory were central to subsequent breakthroughs, being the only institutions capable of producing extremely high-energy environments to test new hypotheses. Today's marvelous private sector advanced chip "fabs" would not exist without generations of government investment in new, open-ended, and publicly available knowledge.

Ideas are different from most economic goods in being infinitely usable (Jones 2023). He argues that the growth rate of living standards ultimately depends on researchers, entrepreneurs, and scientists searching for new knowledge. New ideas have public good characteristics, rarely being fully appropriable by their creators. The absence of complete markets for ideas means that economically rational private firms and inventors underinvest in new technologies relative to the social optimum (Nelson 1959, Arrow 1962). This motivates government intervention in the R&D process. Knowledge spillovers are most obvious in the case of basic research, which is undertaken with no eye toward practical application. Its discoveries can rarely be kept secret. These features offer strong motivation for the government to fund science.

The appropriability problem also motivates intervention later in the technology life cycle. There are knowledge spillovers across firms, which have been documented via patent citation patterns and occasionally productivity and learning-by-doing measures (Jaffe 1986; Trajtenberg 1990; Jaffe, Trajtenberg & Henderson 1993; Bloom, Schankerman & Van Reenen 2013; Covert & Sweeney 2024). The serendipity of the innovation process also means that investment in R&D often yields unintended ideas, which are sometimes poorly suited for the firm and are ultimately deployed by others (Babina & Howell 2023). These spillovers are a reason to subsidize later-stage innovation at firms.

Theoretical work has explored the interaction of optimal tax policy and innovation. Income taxes are designed to generate revenue and redistribute income with minimal efficiency costs, but they can also impact innovation by reducing expected returns for inventors when positive innovation externalities and spillovers are not considered. Stantcheva (2021) models a differentiated tax on both personal and capital income for inventors. With unobserved research productivity, it becomes efficient for governments to use subsidies that decrease in the amount of R&D and taxes that decline with profit. However, with an efficient nonlinear R&D subsidy, an innovating firm can remain close to the optimum even with standard linear corporate income taxes (Akcigit, Hanley & Stantcheva 2022). Stantcheva (2021) also points out that with asymmetric information, optimal policy is dependent on observable characteristics of productivity and spillover; first-best policy may not be possible with real-world observables.

2.1.2. Financial frictions. Financial economics is necessary to understand how frictions prevent projects with positive net present values (NPVs) from receiving adequate funding. Innovation projects are uncertain, often in a sense with no known variance; this makes it difficult to estimate future cash flows (Knight 1921). Outcome probability distributions are in practice fat-tailed; for example, among high-growth startups receiving early stage funding, only a tiny fraction will receive generous returns while most will be written off (Denes et al. 2023).

Compounding this uncertainty is the friction of asymmetric information, which occurs when an agent knows more about the quality of his project than the principal. For example, a startup entrepreneur has more information than a venture capitalist interested in financing her, and an inventor inside a large firm has more information than his boss in the C-suite. Research cannot be completely contracted ex ante, and it is difficult to set up incentive systems that perfectly align with the interests of the principal and the agent (Aghion & Tirole 1994).

A key motivation for government subsidies of small firms or startups is that agency problems and incomplete contracting make innovation more difficult to finance externally than within the firm. Large incumbent firms can finance R&D using retained earnings or by pledging physical assets as collateral (Hall & Lerner 2010). However, younger, smaller firms are more often responsible for radical innovations and the employment and productivity growth that they generate (Acs & Audretsch 1987). Acemoglu et al. (2018) theorize that larger firms focus on incremental innovations to improve existing products, while small firms conduct exploratory innovation. Indeed, Arora et al. (2020) show that innovation has shifted even more toward startups since the 1980s. Yet, early stage startups typically are too risky for debt; with highly uncertain prospects and lacking assets to pledge as collateral, potential creditors are unwilling to accept the downside without any potential upside (Hall & Lerner 2010). Information asymmetry makes arm's-length equity infeasible.

The question that has faced economists is: How severe are these financial frictions? Do they really mean that NPV-positive projects go unfunded? If so, which ones? On the one hand, the venture capital (VC) industry is purpose-built to finance innovation: These equity providers do deep, close-range diligence and ex post monitoring to overcome information asymmetry. They have fund structures designed to profit from the small minority of their portfolios that yield tremendous upside. VC investors also offer value-added services and certification. In practice, VC has been an enormous innovation engine over the past few decades (Kortum & Lerner 2000, Gornall & Strebulaev 2021). A rich literature has established that receiving VC has large, positive impacts on recipient firms (Chemmanur, Krishnan & Nandy 2011; Puri & Zarutskie 2012). Kerr, Lerner & Schoar (2014) find that startup patenting is boosted by investment from angel investment groups when comparing just-funded deals to those missing the cutoff. Moreover, Samila & Sorenson (2011) show that VC investment encourages economic growth in local areas.

Despite the benefits of the VC industry, financial frictions may still hamper startup investment in early stage R&D relative to a social optimum. One possibility is an inadequate supply of VC. This has been an important motivation for governments to directly subsidize or establish VC-type funds. A more nuanced argument is that capital supply is inadequate when an early stage technology is capital-intensive. VCs prefer to run low-cost experiments, leading to a preference for Internet-based platforms. This has had an important impact on the trajectory of innovation (Kerr, Nanda & Rhodes-Kropf 2014; Ewens, Nanda & Rhodes-Kropf 2018). Some of the most socially valuable new technologies (for example, in energy, robotics, quantum computing, or semiconductors) are long-term, capital-intensive projects that are less suitable for VC; in these cases, the private sector cannot overcome financial frictions and government support could be warranted.

2.1.3. Innovation to correct externalities: climate, health, and equity. How do these theoretical rationales map to policy agendas? An important task for economists is to help policy makers choose instruments that address the specific market failure most relevant to a particular context. Furthermore, underinvestment in innovation is more severe when a market suffers from distortions beyond the challenges outlined above. In practice, government intervention in innovation often focuses on policy agendas: high-growth entrepreneurship, defense, climate, health, and education.

High-growth entrepreneurship is often seen by governments as a good unto itself because it yields innovation, which creates knowledge spillovers, but also because startups create employment and local economic benefits (Audretsch & Feldman 1996, Haltiwanger et al. 2016). This leads to technology-neutral policies that aim to encourage local entrepreneurship.

A second agenda is national security. Defense is unique because the ultimate buyer is a monopsonistic government agency providing a public good. This market is narrow but—especially in the United States—historically has a high tolerance for capital-intensive early stage risk-taking and essentially has unlimited buying power. The US military has been an important financier and early customer for transformational technologies such as GPS, radio, cryptography, nuclear power, jet engines, and the Internet (Mowery & Rosenberg 1991, Mazzucato & Semieniuk 2017). The fact that frontier defense technology has always had dual-use (i.e., commercial and defense) components can lead to large opportunities for spillovers from defense R&D investment to the private sector.

Climate and health represent two areas of innovation that have large positive externalities and feature downstream markets that suffer from severe market failures. To address climate change, economic theories with exogenous technological change initially pointed to a Pigovian tax on carbon emissions as the optimal response (Nordhaus 1994). In recent decades, theory has shifted toward directed technical change, where innovation responds to prices and thus can be oriented toward clean and away from dirty technologies (Aghion & Howitt 1996, Acemoglu 2002). The takeaways from this theory work are that optimal policy under endogenous technical change requires the government to intervene earlier in the process and that a carbon tax is not sufficient; instead, research subsidies are necessary (Acemoglu et al. 2012, 2016).

For example, consider a new grid-scale energy storage technology paired with a wind farm. The output is a commodity: electricity. The alternative natural gas power plant has near-certain cash flows, and its electricity output is not differentiated from that of the wind farm. Thus, government research subsidies may be necessary to finance the battery research, since even scientists whose labor is motivated by nonpecuniary goals will need substantial capital to build a prototype. Even after early stage R&D, the first implementation at scale is risky and capital-intensive; the battery may not work as well as the prototype, creating uncertainty about future cash flows.

Project finance is the traditional way to fund the gas power plant, where the assets and future cash flows from the project are the basis of collateral and returns. Clean technology is too risky for project finance debt while also being too capital-intensive and lacking the potential for the outsize returns that VC requires (Nanda, Younge & Fleming 2014). Another challenge at the deployment stage is coordination failure. For example, innovation in electric vehicles might benefit from a national charging network, but automakers might wait too long to collaborate if they cannot easily commit to coordination. For these reasons, promising new technologies often founder in a "valley of death" at the early deployment stage.

Healthcare markets are also special: This sector depends on implicit contracts among the government as a payer, consumers, and firms (Grossman & Hart 1983, Chandra et al. 2016, Gupta et al. 2024). Innovation is distorted by the incentives generated by intensive subsidy in some areas but not others, and what types of treatment and preventive care are priced versus not priced. For example, Budish, Roin & Williams (2015) show that firms excessively focus on late-stage cancer treatments rather than the more socially valuable early stage treatments.

A final rationale concerns distributional equity across geographies, gender, race, and income. Fair access to the opportunity to become an inventor is a good in its own right, but it is also the case that leaving latent talent unexploited is socially costly. Women and minorities are grossly underrepresented among high-growth startup founders (Gompers & Wang 2017; Cook, Gerson & Kuan 2022; Ewens 2022). Howell & Nanda (2023) and Ewens & Townsend (2020) show that gender disparities emerge very early in the startup life cycle, reflecting a dearth of female VCs, which may cause good ideas to go unfunded. In the case of race, Cook, Marx & Yimfor (2022) document several challenges facing Black startup founders, including having fewer VCs in their personal networks and local area. Family income is also related to innovation opportunities; children with parents in the top 1% of the income distribution are 10 times more likely to become inventors than children with parents in the bottom 50% (Bell et al. 2019). Seeking to ameliorate these disparities, governments often target underrepresented populations in their innovation programs.

Inequality across geographies is also a motivating force. The extreme clustering of innovative activity in a small group of wealthy cities such as Boston, Singapore, and Tel Aviv leads governments to believe that they can spur economic growth by bringing research activity to their region. Local governments compete for high-tech firms and central government subsidies by providing their own incentives (Guzman et al. 2023). In recent years, US federal policy has turned to place-based programs. For example, the 2022 CHIPS and Science Act included $10 billion for 20 regional technology hubs in places outside the currently dominant hubs, such as Silicon Valley and Boston, alongside $9.6 billion for Regional Innovation Engines and other centers that aim to support R&D and science-based entrepreneurship (Economist 2023). The challenge facing place-based policies is that innovation benefits from clustering. It may be more efficient to bring underserved people from low-innovation areas to clusters rather than try to create clusters in places without structural advantages (Braunerhjelm & Feldman 2006, Bai et al. 2022).

2.2. The Targeting Tension

Bringing these ideas to practice requires a delicate balance: To be successful, a program must target marginal projects or those that face some type of constraint. These projects are not so promising that they will be privately funded in the absence of the program yet are not so poor quality that they will fail regardless of their financial support. The need to fund marginal projects raises the question of whether to target intervention. A targeted policy such as a grant can focus resources on particular activities that the government wishes to support, perhaps because the project will have large knowledge spillovers and is financially constrained. However, the government faces the same or worse information asymmetry as private funders do and is also subject to forces such as politicization or capture. It is not clear that the government can successfully identify such Goldilocks projects. Public funding with any degree of targeting might also be subject to distortionary political pressure (Hegde 2009). Unlike VCs, government officials are usually not well-positioned to pick winners (Lerner 2009).

A nontargeted policy such as a tax credit is appealing because it allows the market to choose which projects to fund within some large category of investment. However, the cost of subsidizing the same marginal and high-spillover projects will be much higher, as the policy will fund a broader range of projects, some of which are less socially valuable and others of which are not actually financially constrained. Nontargeted policies have a greater risk of crowding out private investment that would have been made in the absence of the policy. Which instrument is more appropriate should depend in substantial part on how much the government can observe (Akcigit, Hanley & Stantcheva 2022).

In practice, the government does not usually talk in the language of market failures but instead focuses on specific agendas, such as entrepreneurship, defense, climate, health, and education. This raises the point about an interest in pushing innovation in a particular direction, if that is seen as being in the national interest. This in turn brings up the possibility that complementarities may exist between capital and labor or that the dimension driving the constraint may not be fully correlated with quality. These factors could imply that intervention may be impactful even if supported projects are not marginal in the traditional sense.

A second tension is between supply and demand for scientists and other workers relevant to R&D, who represent the most crucial innovation inputs. If there are constraints on R&D worker labor supply, wages may increase in response to subsidies such as grants or tax benefits. The result could be no real effects of the tax benefit on innovation (Goolsbee 1998, Van Reenen 2021). In contrast, programs that aim to increase the supply of inventors, such as STEM training funding and research grants to universities, may create a virtuous circle as the additional inventors create new ideas and establish their own firms, which in turn demand skilled workers.

3. ARENAS AND INSTRUMENTS

I next turn to how government intervenes in practice and what we know from the empirical literature about policy effectiveness. I consider policy instruments within the four arenas of firms, financial intermediaries, universities, and government laboratories.

The research reviewed below offers the following conclusions. Subsidies in the form of either grants or tax benefits directed at R&D-performing firms are quite effective at motivating investment and real innovation. In contrast, subsidizing financial intermediaries such as investors in startups does not seem especially promising, though more work is needed. Tremendous benefit can be gained from university-based investment, both to build an educated innovation workforce (i.e., the supply of the most crucial input to R&D, which is scientists searching for new ideas) and to invest in open-ended research that begins in the university lab and spills over to the rest of the economy. Finally, direct government spending may be most useful when it is done in large-scale, moonshot-type programs that aim to coordinate resources. Overall, the benefits of innovation are so large that despite the government's information problems, there does not seem to be reason for shying away from targeted projects.

3.1. Firms

In practice, intervention is most complex and most well-studied for firms. Within this arena, I consider six instruments: grants and loans, tax benefits, prizes, procurement, legal infrastructure, and prices.

3.1.1. Grants and loans. Governments often subsidize innovation with direct grants. I will focus on the important and widely studied US Small Business Innovation Research (SBIR) program, which has been imitated at the US state level and overseas, including at the UK's Innovation Investment Fund, China's Innofund, Israel's Chief Scientist incubator program, Germany's Mikromezzaninfonds and ZIM, Finland's Tekes, Russia's Skolkovo Foundation, and Chile's InnovaChile. Since the early 1980s, 11 participating US agencies have allocated roughly 3% of all R&D expenditure to this program using a staged grant process. Firms first apply for a small initial award (Phase 1). Winners who complete initial work successfully can apply some months later for a larger second phase award.

In early work, Wallsten (2000) compared a group of 367 awardees from all government agencies with 90 rejected applicants to the defense and space agencies and found evidence of crowding out. In a larger and more homogeneous sample but using a matching strategy, Lerner (1999) found positive effects. In Howell (2017), I use comprehensive application data from the US Department of Energy in a regression discontinuity design approach to show that the Phase 1 SBIR awards have powerful positive effects on recipient firms, both doubling their chances of subsequent VC funding and increasing patenting and revenue. The grants appear to fund useful prototyping, as opposed to providing a signaling or certification function. They are more useful for firms typically more financially constrained, such as those that are younger and engaged in clean rather than traditional energy technologies.

More recent work has examined program variation. Using data on state-level SBIR matching grant programs, Lanahan & Feldman (2018) find that SBIR awards benefit younger firms and those engaged in more basic science. In the defense context, Howell et al. (2023) show that while the traditional program requesting highly specific, incremental innovations was not especially effective, a new program that took a more open-ended approach was more successful. This is both because of the openness to new, private sector ideas that could be useful for defense and because the reform program attracted younger, startup-type firms that were new to defense contracting. One issue raised by much of the research on SBIR is lock-in, in which winning increases the chances of another award and yields firms that are specialized at getting SBIR awards rather than seriously commercializing their innovation. In response to these findings, the US Congress has implemented new policies to try to ensure that multiple-time SBIR awardees are working toward commercialization.[1]

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[1]This was accomplished in the SBIR and STTR Extension Act of 2022, available here: **https://www.congress.gov/bill/117th-congress/senate-bill/4900/text**.

Evaluations of innovation grant programs elsewhere in the developed world have found positive effects, especially for firms that are likely more financially constrained. For example, Lach (2002) finds that an Israeli R&D subsidy has strong positive effects on small firm innovation spending (i.e., crowding in private investment), but negative effects among large firms (i.e., crowding out). Other examples include Almus & Czarnitzki (2003) with data from eastern Germany, Bronzini & Iachini (2014) with data from Italy, and Jaffe & Le (2015) with data from New Zealand. A counterexample is from China, where Wang, Li & Furman (2017) study the Innofund subsidy program, which was largely modeled on SBIR. They observe that higher quality firms select into the program, but there is no causal effect of winning on innovation. They suggest this could reflect politicization of the program.

Researchers have done little work on the effect of credit instruments, which include loans and loan guarantees for R&D-performing firms. This is an area in which finance researchers can add value by evaluating programs and their mechanisms. The United Kingdom, France, and Germany offer subsidized loans to innovative small firms. Some governments, such as Israel, France, and Finland, provide grants to startups that must be repaid if the startup earns sufficient revenue.

Overall, it is important to target direct subsidies toward financially constrained firms with growth opportunities, such as young firms. When grant programs largely fund older, established firms, which seems to be the case in the defense sector (Wallsten 2000, Howell et al. 2023), they may fail to target sufficient numbers of those marginal firms that are constrained but have high-quality projects and thus do not have strong positive effects on innovation.

3.1.2. Tax benefits. Tax subsidies for R&D-performing firms are widely used around the world. Among 42 Organization for Economic Cooperation and Development (OECD) and European Union (EU) countries surveyed in 2018, 33 had significant tax benefits for R&D spending by firms, with the United States having a relatively low benefit and Portugal, Chile, and France having very large benefits (Appelt, Galindo-Rueda & Gonzáles-Cabral 2019). Tax benefits are usually less targeted and more politically appealing than direct spending. Of course, they similarly reduce tax revenue that could alternatively be directed elsewhere, and not targeting may facilitate crowding out.

Empirical work finds that tax subsidies causes firms to report more R&D spending, with elasticities of at least one. For example, Dechezleprêtre et al. (2016) establish a causal link using a regression discontinuity design based on changes in asset-based size thresholds for tax subsidy eligibility in the United Kingdom. They estimate that the policy stimulated £1.7 of R&D for every £1 of subsidy. There are also positive effects on patenting.[2] In the United States and studying pre-1990 data, Hall (1993) and Rao (2016) both estimate R&D tax price elasticities of a bit more than one in the short run. Other global evidence supports these magnitudes of roughly one unit of elasticity in the long run (Bloom, Griffith & Van Reenen 2002). Implicit evidence of knowledge spillovers from tax credits has been found. Bloom, Schankerman & Van Reenen (2013) and Babina & Howell (2023) use US tax credit changes to instrument for R&D and find positive spillovers to competing firms and employee-founded startups, respectively, suggesting that there are knowledge spillovers from tax credits.

As with grants, the tax credit literature finds larger effects when policies target financially constrained firms. Rao (2016) and Dechezleprêtre et al. (2016) find that smaller and younger firms are more responsive. In the same vein, Agrawal, Rosell & Simcoe (2020) find that small firms and those with lower fixed costs are more responsive to R&D tax incentives.

[2] Guceri & Liu (2019) confirm these findings but with slightly lower magnitude, showing over the same period that the UK tax credit led to approximately £1 of additional R&D for every £1 of forgone corporate tax revenue.

Two concerns with tax credits are relabeling and geographic reallocation. Chen et al. (2021) examine a Chinese policy that substantially reduced corporate tax on firms above an R&D investment threshold (also a notch-based policy like the one studied in the United Kingdom). This generates bunching near the notch, reflecting some relabeling. Although they found that relabeling accounted for approximately 25% of reported R&D, they also calculate large productivity benefits from greater R&D. This evaluation offers a good example of how optimal policy may deviate from first-best depending on what the government can observe (Stantcheva 2021). While in principle a linear tax credit might be preferred, Chen et al. (2021) show how a notch-based policy will be more effective because the government can apply its limited monitoring effort around the notch, rather than across all firms.

Firms and inventors may shift R&D geographically to benefit from tax credits. This has been found both across states in the United States and internationally (Akcigit, Baslandze & Stantcheva 2016; Moretti & Wilson 2017). Wilson (2009) finds that a one percentage point increase in a state's effective R&D credit rate leads to a long-run increase of R&D spending of 3–4% inside the state and a decrease of 3–4% outside of it, implying nearly all increases in R&D come at the expense of a state's neighbor. Moretti & Wilson (2014) assess the impact of R&D tax credits on biotech companies and their innovation clusters, finding that a 10% reduction in the user cost of capital due to R&D tax credits and subsidies generated a 22% increase in star inventors. However, this was due mostly to relocation rather than the increased productivity by state incumbent inventors.

Firms are often eligible for multiple innovation subsidy instruments. In one of the only papers on how instruments interact, Pless (2023) shows that grants and tax credits have complementary effects on R&D investment but only among firms expected to be financially constrained. Broader tax policies, including income taxes and investment incentives, can also affect innovation. Using patent-based outcome measures, Akcigit et al. (2019) find that higher personal and corporate taxes in the twentieth century reduced innovation quantity and the mobility of inventors but left average quality intact. Atanassov & Liu (2020) show that corporate tax cuts may increase innovation quantity and quality, also using patent-based measures. Beyond patents, higher corporate tax rates also lead to less investment and less entrepreneurship (Djankov et al. 2010; Da Rin, Di Giacomo & Sembenelli 2011; Giroud & Rauh 2019).

3.1.3. Prizes. Inducement prizes represent a demand-pull instrument, where an organizer seeks a specific technological goal and offers a purse to the contestant who produces the first or best solution. Prizes can compensate inventors for the social value of their work in settings with inadequate intellectual property (IP) protection or demand (Kremer 1998). Prizes can focus many innovators on the same problem and can attract diverse talent (Brunt, Lerner & Nicholas 2012). The term inducement differentiates these prizes from ex post recognition prizes, such as the Nobel Prize, which can also lead to more follow-on innovation (Moser & Nicholas 2013). It has been argued that inducement prizes are superior to patent protection for some types of inventions (Stiglitz 2007, Kremer & Williams 2010).

One early example of a prize is Napoleon's offer to pay 12,000 francs for a food preservation technology; his soldiers were going hungry as their supply lines stretched across Europe (Gallo 2018). In the United States, NASA and the Defense Advanced Research Projects Agency (DARPA) are known for prize programs. For example, DARPA's Grand Challenge program for autonomous ground combat vehicles led to important advances in autonomous technology, possibly only via the collaboration of experts who do not usually participate in defense contracting, including academics and startup entrepreneurs (Urmson et al. 2009). Similarly, Lakhani et al. (2013) shows that a prize for a biologic algorithm attracted the type of big data computational specialists needed to solve the problem, who were otherwise not available in the life sciences.

Boudreau, Lacetera & Lakhani (2011) theorize about how the number of competitors affects effort. They point out that if more contestants are allowed to participate, it will reduce the chance of winning and thus effort but will increase the chance of finding an extreme-value solution. They conclude that it is better to have more competitors when problems are highly uncertain. In a field experiment with a life sciences firm, Zivin & Lyons (2021) put a design question into practice for developing a piece of software. They find that winner-take-all prizes improve innovation quality and novelty relative to sharing the same prize money across multiple top submissions.

3.1.4. Procurement. Governments, especially via defense and space agencies, often purchase goods and services with embedded innovation. This procurement is an important demand-pull channel to generate innovation that the private sector will not fund. Historically, defense procurement has been a crucial engine of innovation. Gross & Sampat (2023) document the important jump-starting effect of World War II expenditure at the US Office of Scientific Research and Development. The surge in R&D procurement from this office had long-run effects, catalyzing key technology clusters that have endured to the present day and changing the trajectory of US innovation. Today, the US Department of Defense (DoD) is the largest single investor in R&D in the world and comprises approximately 60% of the total US federal government R&D (Sargent & Gallo 2018). In 2015, the US government awarded $37.5 billion in R&D contracts, relative to a total of $3.6 billion in all federal grants to firms (Belenzon & Cioaca 2021).

Howell et al. (2023) document dramatic consolidation among prime defense contractors in recent decades, accompanied by a decline in innovation quality relative to the private sector. This has occurred despite a substantial increase in prime contractors' profits and assets. They examine a program reform at the US Air Force that evaluates whether to specify desired products (a conventional approach) or allow firms to suggest ideas (an open approach). Using a US Air Force R&D grant program where open and conventional competitions were held simultaneously, Howell et al. (2023) find that open awards increase the chances of a subsequent downstream DoD contract by approximately 50% of the mean and also increase other measures of novel innovation. The results suggest benefits from open approaches to innovation procurement.

Using data from across the US government, Belenzon & Cioaca (2021) show how guaranteeing demand downstream with government procurement contracts increases R&D upstream; firms are willing to invest to win an R&D race so that they can be awarded the lucrative contract. This crowding-in effect, however, requires the government to contract both for the R&D and the ultimate product. Che, Iossa & Rey (2021) come to a similar conclusion from a theoretical perspective. Beyond the United States, Moretti, Steinwender & Van Reenen (2020) also find that increases in military R&D spending have crowding-in effects in OECD countries, positively affecting private R&D.

Drug and especially vaccine development is another area where procurement can change the direction of innovation. The case of the COVID-19 vaccine is an excellent example. Lalani et al. (2023) document that the US government invested at least $31.9 billion to develop, produce, and purchase mRNA COVID-19 vaccines, which included funding clinical trials and offering advance purchase guarantees for hundreds of millions of doses. These initiatives mitigated misaligned incentives in the drug development process. Left to its own devices, the private market produced too many COVID-19 therapies—incremental improvements on existing drugs—at the expense of new vaccines, which would have been more socially useful but have lower expected profits (Bryan, Lemus & Marshall 2022).

3.1.5. Legal infrastructure. This section provides an abbreviated introduction to the many ways in which legal and regulatory infrastructure shapes innovation.

3.1.5.1. *Antitrust enforcement.* Antitrust (or competition) policy helps an economy to innovate through the Schumpeterian creative destruction process, enabling disruptive new ideas to challenge established incumbents who would otherwise monopolize or engage in anticompetitive behavior (Federico, Morton & Shapiro 2020). Cunningham, Ederer & Ma (2021) study "killer" acquisitions where pharmaceutical firms acquire competing drugs in order to shut them down. Consistent with an important role for antitrust policy, these acquisitions occur disproportionately just beneath the threshold for merger review (also see Wollmann 2019). And Kretschmer, Miravete & Pernías (2012) find that more competition among automobile dealers increased software adoption. However, increasing competition in a market can reduce innovation when it leads firms to have less free cash flow to invest in new ideas or when there are large spillovers to competitors (Gilbert 2006, Vives 2008). Using data from antitrust cases, Kang (2019) finds that antitrust enforcement actions reduced innovation among colluding firms.

The Bell System is a useful case study of antitrust policy and innovation. Before its breakup in 1984, Bell was a vertically integrated telecommunications company controlling over 85% of US telephone services and the largest private employer in the United States. Watzinger et al. (2020) study a 1956 requirement that Bell license all its existing patents royalty-free, imposed following an antitrust lawsuit that successfully argued Bell was foreclosing access to the equipment market. They find that the free access to Bell's patents permanently increased innovation but only outside the telecommunications sector, since Bell retained its monopoly. In a follow-up paper, Watzinger & Schnitzer (2022) document that, consistent with monopoly power reducing innovation incentives, the 1984 breakup caused a dramatic and long-term increase in invention quality and quantity in telecommunications, driven by firms outside the Bell System.

3.1.5.2. *Intellectual property protection.* One of the oldest forms of government intervention in innovation is the patent system, which originated in fifteenth-century Venice (Adams 2019). Government can incentivize knowledge creation by attaching and enforcing property rights on new ideas. Patents give inventors the exclusive rights to monetize their ideas. While patents incentivize private R&D, they also engender monopoly pricing and block knowledge spillovers (Scotchmer 1991, Boldrin & Levine 2013). A striking example is Williams's (2013) case study of the firm Celera's short-term IP rights over human genes. Even though it was known that the Human Genome Project would make Celera's genes publicly available 2 years later, Celera was nonetheless able to earn large fees from data and licensing deals. Relative to a counterfactual of Celera genes having always been in the public domain, Williams (2013) finds that IP protection reduced scientific research and new products by 20–30% in the short-term. In contrast, open access mandates for medical research findings have been shown to increase subsequent patent citations to that research by as much as 50% (Bryan & Ozcan 2021).

The patent system, even in the United States, which has strong property rights, is insufficient to establish a complete market for ideas. Many types of IP are protected via trade secrets, for example. Interestingly, the absence of well-functioning markets for ideas may be central to the creative destruction process, where new firms compete with old firms that have outdated technology (Schumpeter & Redvers 1934). Gans, Hsu & Stern (2002) theorize that if markets functioned efficiently through licensing, partnerships, and acquisitions, it would be optimal for startups and incumbents to cooperate on commercialization rather than duplicate distribution investment and compete away existing market power. The fact that a startup cannot protect its IP when cooperating leads to more competition.

Patent boxes, used by many European countries, are policies that reduce tax rates on corporate revenues that the firm attributes to intellectual property in the form of patents. Empirical work indicates that patent boxes do not meaningfully incentivize additional R&D or innovation and instead lead to tax competition and the relocation of where firms report their revenue (Griffith, Miller & O'Connell 2014; Gaessler, Hall & Harhoff 2021).

3.1.5.3. Noncompete laws. Employees—especially those involved in innovation—accrue tacit, firm-specific knowledge that is important to their firm's ongoing productivity and ability to innovate. Wishing to prevent departures, in particular to competitors, firms often require new employees to sign noncompete agreements, which restrict their ability to join a competing firm in the local area if they resign. On the one hand, this likely benefits innovation at the parent firm by creating some monopsony power over knowledge workers, not unlike the function of a patent. On the other hand, by reducing job mobility, these covenants hamper a crucial means of knowledge spillovers, via employees moving between firms, and especially employees leaving large firms to found startups (Babina & Howell 2023). In practice, many states refuse to enforce noncompete covenants, including California, creating some degree of jurisdictional competition. No strong evidence about how enforcing noncompetes affects innovation has been found; work has focused instead on startup creation and labor mobility (e.g., Marx, Strumsky & Fleming 2009). More research in economics is warranted.

3.1.6. Prices and induced innovation. The final instrument I will discuss is the demand-pull effect of adjusting prices. Prices affect innovation by changing the relative costs of inputs for producers or substitute goods for consumers (Hicks 1932). This induced innovation hypothesis is perhaps most relevant and best studied in the setting of pollution and climate change. In Section 2, I introduced the importance of directed versus exogenous technical change to optimal policies seeking to combat climate change. There are many instances of pollution taxes or trading systems, including the NO_x and SO_2 markets in the United States and carbon prices in Europe, China, and elsewhere.

To understand how prices affect innovation, one approach is to estimate a patent-to-price elasticity. In the first work along these lines, Popp (2002) found a large patent elasticity in fuel prices, and more recent research has confirmed the relationship. For example, Knittel (2011) shows that gasoline price increases drove a 60% improvement in passenger vehicles in the United States between 1990 and 2006, after controlling for vehicle weight and power. Aghion et al. (2016) find that an elasticity of alternative fuel patents to gasoline prices is nearly one. They also document path dependency: The automobile firms most responsive to price increases were already working on clean energy. Newell, Jaffe & Stavins (1999) take a different approach by using product characteristics as an outcome; they find that prices change the direction of innovation but not the rate.

The EU's Emissions Trading System established a carbon price for electricity generation and manufacturing starting in 2005. The evidence is mixed. While Calel (2020) found that the carbon price increased climate-related patenting, low and volatile prices seem to have engendered mostly incremental efficiency and installation improvements rather than major deployment of new inventions (Gulbrandsen & Stenqvist 2013; Borghesi et al. 2015; Kim, Heo & Kim 2017). This highlights a downside with market-based price instruments: They must be certain and high enough to motivate the desired private investment in radical innovation.

3.2. Financial Intermediaries

Subsidizing intermediaries, especially through the tax code, is attractive for several reasons: no need for government to pick winners, low administrative burdens, and market incentives with investors retaining skin in the game. VC and angel investors, who fund startups, are obvious targets given their important role in the radical innovation ecosystem (Hall & Lerner 2010; Da Rin, Hellmann & Puri 2013). Promoting innovation and entrepreneurship are the rationales used to justify a low rate of taxation on carried interest in the United States (Howell & Gupta 2023). Yet, as with subsidies for R&D performers, such benefits could crowd out private investment; the subsidy might only yield rents for the intermediary, who would have made the same investments in its absence.

Empirical literature finds evidence that supporting intermediaries crowds out private investment, in contrast to the findings on support for R&D performers. Denes et al. (2023) study angel investor tax credits, which are used by at least 14 countries and most US states. While the programs increase reported angel investments, they do not generate high-tech firm entry or job creation. One reason is selection: Additional investment flows to relatively low-growth firms. The new angel investments would have happened in the absence of the policy as informal equity, often purchased by insiders in the firm or family members of the entrepreneur. A second reason flows from the theory of investment in early stage, high-growth firms with fat-tailed returns. As the right tail of big successes grows fatter, professional investors become less sensitive to the tax credits.

Beyond tax policy, some countries, such as Canada, Israel, and Australia, have established wholly government-backed funds. A more market-oriented approach is to create government funds-of-funds that invest as one of many LPs in private funds or offer matching funds to private VC firms. Canada has perhaps the largest and most diverse government interventions to support the VC industry. They have subsidized largely private VC firms and have built government-owned and -managed VC programs through the Business Development Bank of Canada (BDC). Specifically, the BDC both operates internal VC funds and subsidized a certain type of Canadian VC fund called Labour Sponsored Venture Capital (LSVCC), which are essentially tax-subsidized mutual funds that invest in startups. Using data from the late 1970s through 2011, Cumming & MacIntosh (2006) find that LSVCC funds crowd out private VC, producing no effect on high-growth entrepreneurship. Consistent with this, Brander, Egan & Hellmann (2010) show that Canadian startups backed by private VC rather than government VC are also more innovative, create more value, and are less likely to fail. However, Brander, Egan & Hellmann (2010) take a more nuanced view on crowding out and point out that government-backed VC can still be worthwhile, promoting market expansion to somewhat lower quality firms. In part as a response to this line of research and other evidence, the BDC eliminated the tax subsidy for LSVCCs and shifted its internal program in the 2010s toward providing higher-powered compensation to the government-employed general partners.

There is similar evidence from Europe. Cumming, Grilli & Murtinu (2017) compare independent private and government-backed VC firms and find that the former outperform the latter. In a similar vein and also using European data, Grilli & Murtinu (2014) find no evidence that receiving investment from a government-backed VC firm affects portfolio firm performance. One reason for the failure of government-backed VC is that the managers often have political rather than purely financial motivations, or they are not compensated competitively and thus do not have the same skills and level of effort as private VCs. While existing evidence offers a good start, this topic merits further research.

Another tool to support intermediaries is loan guarantees for lenders. One well-known example of a loan guarantee program is at the US Department of Energy, where loan guarantees have funded clean energy projects at both large incumbents and startups. The hope for loan guarantees is that they will substitute for collateral among constrained firms with promising innovation projects. Whether credit is helpful in this context depends both on whether the lender responds with greater credit supply (i.e., that the subsidies do not crowd out private finance) and whether the recipient firms carry out the desired innovation and are able to repay the loan. Loans impose new demands on firms, increasing leverage and requiring cash-to-service interest payments. If a project is long-term before generating revenue, a loan might be counterproductive and hasten failure.

Existing research has primarily studied the effect of loan guarantees on entrepreneurship more generally. In studies of loan guarantee program expansions, Lelarge, Sraer & Thesmar (2010) and Lagazio, Persico & Querci (2021) find contrasting effects: The former paper finds using French data that expanding to more industries had positive effects on growth among newly eligible firms, while the latter paper finds that expanding eligibility of an Italian program had negative effects due to debt overhang. One possible explanation is that this occurred after Italy's sovereign debt crisis, and loans were allocated to firms that could not manage additional debt. In this case, a grant instrument might have worked better, if it could be targeted to firms that were not zombies. Regarding the first question of lender supply, Bachas, Kim & Yannelis (2021) document a large elasticity of bank lending volume to loan guarantee generosity in the US Small Business Administration's program. More work is needed on the relationship between loan guarantees and innovation.

3.3. Universities and Human Capital Investment

Universities are crucial engines of innovation, producing new ideas through the research they perform and training scientists through their education mission (Weinberg et al. 2014). Worldwide, universities are enmeshed with government. They are typically public institutions, receiving most or all of their funding from the government. In the United States, private research universities are also dependent on the government through three policy instruments: (*a*) tax-exempt status; (*b*) tuition subsidy via grants and guaranteed loans to students; and (*c*) research grants. Since World War II, federally funded basic research at US research universities has been at the center of the nation's innovation ecosystem. These federal research grants represent the core funding for hard sciences at US research universities. One reason university research is so important is because it is often conducted as a general, open-ended inquiry with no particular application in mind. The novelty and serendipity of this type of inquiry are often the source of breakthrough technologies (Azoulay & Li 2022).

Longstanding literature traces spillovers from universities to the local private sector, helping to explain the clusters of high-tech firms around research universities (Jaffe 1989, Audretsch & Feldman 1996, Belenzon & Schankerman 2013, Kantor & Whalley 2014, Tartari & Stern 2021, Hausman 2022). Important dimensions of the university production function are less well-studied, such as whether education or research drives spillovers, whether researchers can easily substitute other sources for federal funding, and whether the intensive margin magnitude of research funding is important for innovation output. The answers to these questions can help shape policy choices about what dimensions of universities deserve government subsidy.

Existing work on the effect of the magnitude of funding is mixed (Adams & Griliches 1998, Tabakovic & Wollmann 2019, Myers 2020). Jacob & Lefgren (2011) and Azoulay et al. (2019) study the effects of US government grants from the National Institutes of Health (NIH) to academic researchers, using similar data on applications in the roughly 1980–2000 time frame and regression discontinuity designs based on NIH funding rules. Jacob & Lefgren (2011) find only small effects of NIH grants on publications at the individual scientist level. They conclude that when researchers lose an NIH grant, they usually can shift to another source of funding. In contrast, Azoulay et al. (2019) find large effects of NIH grants on private sector patents. By linking publications to grants and patents to publications, they show that an additional $10 million in NIH grants leads to 2.3 additional patents from pharmaceutical and biotechnology firms. They use disease-science-level rather than individual-level data, which may account for some of the difference relative to Jacob & Lefgren (2011). The near-winners who serve as the control group in

Jacob & Lefgren (2011) may be better quality and thus access alternative funding more easily than the unfunded researchers driving variation in instrumented analysis such as that by Azoulay et al. (2019) or Tabakovic & Wollmann (2019).

A different perspective on government support for universities is to ask what happens when federal funding declines. Babina et al. (2023) link data on all employees of grants at 22 universities to career outcomes of individuals in the US Census Bureau's Internal Revenue Service W-2 files, patent inventors, and publication authors in the PubMed database. We find that a negative federal funding shock nearly halved a researcher's chance of founding a high-tech startup but doubled their chance of being an inventor on a patent. The shock also reduced the number of publications, especially those that are more basic, more cited, and in higher-impact journals. These findings seem to in part reflect a shift from federal to private funding. While federal awards assert no property rights, private firms have incentives to appropriate research outputs, and for that reason they employ complex legal contracts with researchers. As the composition of research funding shifts from federal to private sources, outputs are more often commercialized by the private funder rather than disseminated openly in publications or taken to a startup by the researcher.

This issue of funding sources relates to how university research is commercialized and who has the right to appropriate it. Since the Bayh-Dole Act of 1980, universities in the United States have the right to own and patent federally funded research outputs. They have to determine how to share these rights with researchers. Lach & Schankerman (2008) find that stronger royalty incentives for faculty scientists in US universities lead to increased license income, especially at private institutions. These investments primarily enhance the quality of inventions rather than their quantity. Other countries face the same tension. In Norway, Hvide & Jones (2018) use a natural experiment to show that when university researchers lose full rights to their innovations, entrepreneurship and patenting rates decline by 50%. Quality measures related to these ventures also decline.

Less work has been done on how the education and training side of the university affects innovation, especially in connection with government support. In Section 2.2, I noted that education funding might increase innovation more efficiently than subsidies to R&D performers if innovative labor supply is constrained. Romer (2000) argues that education institutions have failed to respond to performer subsidies with high-quality training. He prescribes a more active role for the government in training scientists and engineers, suggesting that subsidies be reallocated away from firms and toward education. Little empirical work has been done on this broader training function, but we do have evidence about doctoral training. Zolas et al. (2015) show, using individual tax data, that funded doctoral programs yield high-quality industry jobs, especially near the university. In particular, looking at eight universities, they find that 40% of science doctorates between 2009 and 2011 obtained jobs in industry. Tham et al. (2024) examine interruptions in large NIH grants and show that these interruptions reduce job placement outcomes, increasing unemployment and emigration. These papers, alongside Babina et al. (2023) and others, use data from the Institute for Research on Innovation and Science (IRIS) and Universities: Measuring the Impacts of Research on Innovation, Competitiveness, and Science (UMETRICS) project at the University of Michigan.[3] This project has enabled a burgeoning literature on university innovation, which highlights how data availability can shape the direction of research.

[3]For more information, see **https://src.isr.umich.edu/projects/institute-for-research-on-innovation-and-science-iris/**.

3.4. Government Research and Moonshot Missions

In this final section, I consider the most direct form of government intervention in innovation: the public provision of research. This occurs at national laboratories such as the US Department of Energy's Lawrence Livermore National Laboratory or the French National Centre for Scientific Research.[4] National labs conduct research ranging from basic science—which leverages major capital investments such as telescopes or particle accelerators—to highly applied development, particularly in the defense sector at facilities such as the US Army Research Laboratory. Government labs also are located in diverse areas, some in innovation clusters and others in rural, isolated places. Little research has been done on the impact of national labs. Jaffe & Lerner (2001) focus on the commercialization of research out of national labs. They show that, after policy changes designed to encourage patenting and licensing in the early 1980s, by 2000 national labs achieved parity with research universities in the number of patents produced per R&D dollar spent.

Anecdotal evidence shows that big-dollar, mission-oriented government research programs have large spillovers (Mazzucato 2021). These programs aim to achieve a specific technological goal, such as landing on the moon or building a nuclear weapon. The race to beat the Soviet Union to the moon entailed an enormous federal R&D outlay that was concentrated in one agency and highly coordinated, unlike the diffused and fragmented approach of normal times. During the mid-1960s, NASA employed more than 400,000 workers and had funding of approximately 0.7% of US GDP (Weinzierl 2018). Kantor & Whalley (2023) compare industry–county pairs that were already specializing in space-related technologies to those that were not before and after the windfall R&D spending during the Cold War Space Race. They find that the moonshot increased manufacturing's value-added, employment, and capital accumulation in space-related sectors but do not find beneficial spillovers into other colocated industries.

In recent years, large-scale industrial policy that pulls together multiple interventions, often with a place-based component, has become increasingly popular around the world. Examples include the Inflation Reduction Act and the CHIPS and Science Act in the United States, the EU's New Industrial Strategy, South Korea's New Deal, and the Made in China 2025 initiative. The CHIPS and Science Act represents a potentially historic investment in advanced manufacturing and R&D in the United States. It includes efforts to create regional technology hubs, combining large-scale subsidies for semiconductor manufacturing with science funding and job training programs, among other things. It is difficult to measure the impact of such policies using the standard tool kits in financial economics. Researchers might consider collaborating with economic historians or finding ways to combine narrow causal analysis of particular policies with careful descriptive work on the overall program.

4. FUTURE DIRECTIONS

Innovation policy is an area where research in financial economics can be particularly impactful. Program evaluations conducted by academic economists frequently find their way directly into policy justifications and new programs. This is only more true as governments in the developed world increasingly embrace industrial policy with a strong emphasis on science and technology leadership.

In this closing section, I wish to stress a few key themes that emerge from the literature thus far and then point to areas that deserve more attention. First, the evidence points to large benefits

[4]In the United States, a distinction is made between national labs and Federally Funded Research and Development Centers, which are managed by nongovernment firms or nonprofits but receive all their funding from the government. An example is NASA's Jet Propulsion Laboratory, which is managed by Caltech.

from public sector R&D grant funding for university science and for young, high-tech firms. The government has a key role to play in the type of failure-tolerant, open-ended research that yields breakthrough inventions (Manso 2011, Azoulay & Li 2022). Tax credit literature has also affirmatively established that tax credits to R&D-performing firms yield more R&D investment.

In contrast, the literature on subsidizing financial intermediaries, such as VC or angel investors, finds more modest or no benefits. More work here is needed, especially in areas such as tax-subsidized or partially government-funded private equity funds, which have been a focus of Chinese technology policy, and loan guarantees to support innovation, such as the US Small Business Investment Company program. Here, financial economists are well-positioned to contribute.

Going forward, future research might address three concerns. First, there is little study of how risk can be shared in ways that align incentives to promote socially useful innovation. Risk-sharing instruments include subsidies for debt (i.e., loans or loan guarantees) or for VC investors. This is an area where financial economics is particularly relevant. A second is the measurement of innovation. Current literature relies too heavily on patents as an outcome measure, given their important limitations in capturing innovation (Lerner & Seru 2022). Researchers need to develop better outcome variables that capture the deployment of new technologies and their real economic impact on objectives of interest. The third is the "desk drawer" problem, where null results are unreported. Editors can address this by committing to publish null results from well-identified program evaluation proposals.

Finally, beyond addressing these concerns, there are two especially promising avenues for future work in financial economics. One is a rigorous evaluation of the most direct forms of government intervention, which are widely used but understudied. This includes procurement, prizes, and direct public provision at national labs. The second is work that explores how different instruments interact over the technology life cycle. For example, a technology might be born through a basic science grant to a university, developed in part at a national lab, adapted for private use by a startup funded with an R&D grant, and, finally, deployed at scale by a large firm benefiting from an R&D tax credit. Do these programs feed off of and depend on one another? Or can we fund innovation more efficiently by reallocating from one existing instrument to another? Studies that marry the theoretical predictions with policy evaluation and go beyond evaluating a single instrument at a single point in the technology life cycle will be especially useful.

DISCLOSURE STATEMENT

The author is not aware of any affiliations, memberships, funding, or financial holdings that might be perceived as affecting the objectivity of this review.

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