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Federal funding and the rate and direction of inventive activity☆

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ABSTRACT

Leveraging a new measure of patent citation trees (Corredoira and Banerjee, 2015), we demonstrate that research funded by the federal government is associated with more active and diverse technological trajectories. Our findings tie government funding to breakthrough inventions. The differences are especially evident at the upper percentiles of the distribution of long term patent influence and stem primarily from research conducted outside the federal government and sponsored by the DOD, HHS and NSF. Government funded patents are inputs into a broader range of technologies. Additional analyses indicate that federal programs invest in some technological areas that private corporations eschew, and federally funded university patents are in different technological classes than non-federally funded university patents. In this sense, the government may play an irreplaceable role in the rate and direction of inventive activity.

"Generally speaking, the scientific agencies of Government are not so concerned with immediate practical objectives as are the laboratories of industry nor, on the other hand, are they as free to explore any natural phenomena without regard to possible economic applications as are the educational and private research institutions." - Vannevar Bush, Science the Endless Frontier", 1945.

1. Introduction

The Federal government funds 30% of US research and development (R&D).[1] However, since 2010, US government spending on research and development has remained flat and R&D funding in real terms has declined (Sargent, 2015). Vannevar Bush's 1945 Report to the President first articulated the basic logical argument for government funded R&D.[2] Nelson (1959) and Arrow (1962) explored the welfare reasons to support Bush's policy recommendations. Nelson suggested and Arrow formalized the idea that the government might play a role in sponsoring R&D because the private sector is likely to underinvest in R&D due to difficulties in appropriating returns to particular projects. The appropriability problem is exacerbated by the technological riskiness of innovative projects that reduce expected private value. Ideally, government investments should focus less on the near-term private return and more on the long-term public welfare. In this sense, government's support for difficult-to-appropriate technologies whose direct and indirect influence may unfold over a long period of time would not have been superseded by private investors that lack the incentive to do so. A lengthy literature has explored this fundamental proposition and measured the returns to R&D spending, the indirect effects of government research spending on private sector research spending, the nature of spillovers and the diffusion of knowledge through citation

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[1] The statistic refers to the latest available year, 2011. National Science Foundation, Science and Technology Indicators (2014). Chapter 4. http://www.nsf.gov/statistics/seind14/index.cfm/chapter-4/c4h.htm.

[2] Bush writes, "Industry will fully rise to the challenge of applying new knowledge to new products. The commercial incentive can be relied upon for that. But basic research is essentially noncommercial in nature. It will not receive the attention it requires if left to industry.", Ch. 3. This logic still appears in government policy documents (Sargeant, 2015).

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patterns. In general, most methods and assumptions show a strong positive private return to R&D spending, and some evidence of spillovers from the public to the private sector (Hall, Mairesse, and Mohnen, 2009).[3]

If the federal government is indeed financing projects whose value is more difficult to appropriate in the short term than those funded by private enterprise, we would expect to see the value of federal funded projects to emerge over time. Due to data limitations, prior research has focused comparisons not on who is funding innovation, but rather where this innovation is taking place. For example, this proposition has been tested by comparing patents, which is the central measurable inventive output that both for-profit and non-for-profit organizations produce. However, Henderson, Jaffe and Trajtenberg (1998) found that university patents, largely funded by the federal government, were, on average, declining in importance throughout the 1980s and early 1990s, as measured by first generation patent citations. Mowery and Ziedonis (2002) found no decline among patents of two leading universities before and after the 1981 Bayh-Dole Act while Mowery, Sampat and Ziedonis (2002) found evidence that part of the measured decline in citations to university patents in the 1980s was reversed.

We revisit this question and address several limitations in the literature. First, we directly observe whether the research and development behind a patent was financed by the federal government. Knowing who funded research sets us apart from most prior literature that primarily focuses on where the research took place but not who funded it. This immediately leads us to explore a wide range of second-order questions concerning the institutional differences of the federal funding of innovation. For example, does patent performance change with the funding mechanism? Is there variation by federal agency? Given that agencies and agency programs have different goals, we might expect varying incentives are associated with varying outcomes. Unpacking any second-order differences is critical as agencies are treated differently in science policies.

Second, we adopt a more inclusive measure of the long-term value of patented inventions. The measure, *influence,* takes into account both the number of patents in the multi-generational forward citation tree as well as the intraconnectedness of the tree's structure over a defined time period.[4] *Influence* is particularly appropriate for patents because unlike authors of academic papers, inventors and their agents are only required to cite the immediate precedents of inventions and have no incentive to cite anything more than necessary (Corredoira and Banerjee, 2015; Nagaoka et al., 2010). While first generation citations, which we label *impact*, and *influence* are correlated to some extent ($r < 0.2$), a significant share of highly influential patents do not enjoy high levels of first generation impact.[5] This indicates that direct forward citations alone do not capture the full picture of how a particular invention may affect technological trajectory over the long term. In addition to offering the proper setting for the measurement, patents also offer a more conservative estimate of the value of federally funded research, if one were to believe that the majority of the products of federal R&D are in the form of research papers in basic science and that private sector is more incentivized to patent efficiently.[6] Being an intergenerational measure, *influence* allows us to also ask whether the future generations are broad.

We then adapt the generality measure introduced by Hall, Jaffe and Trajtenberg (2001) to accommodate multiple generations of forward citations. The Arrow-Nelson ideal implies government sponsorship of more fundamental technologies which are then likely to have utility across a broader range of applications. In contrast, the technologies developed through private funding may have more specific applications, which facilitate appropriation of private value. Generality measures how broad the distribution of citing patents across knowledge fields is. Extending the measure allows us to ask whether the funding source of a patent is related to the breadth of its seminality.

Third, our analysis of 4311 federally funded patents across multiple agencies relies on a flexible and precise, bootstrapping matching strategy. Matching allows us to ask whether federally funded patents are different than those funded by the alternative entities *conditional* on technological area, though this limits our ability to make unconditional statements and further inference on the general efficiency of various external organizations. The results of the bootstrapping strategy are not subject to the loss of information of arbitrary choice from multiple potential matches. This allows us to avoid spurious results based on a certain set of match choices.

Our results indicate that federal funding is associated with the *rate* of innovation: applied research funded by the US federal government is more likely to be the starting point of active technological trajectories in both the near and long terms. As compared with patents not funded by the government, the most seminal federally funded patents are conducted by external organizations such as universities and are associated with 10% to 104% more *influence*. The result is not found across all settings and agencies. For example, patents emanating from in-house research done by the federal government may be *less* influential. At the same time, patents stemming from research funded by all agencies and conducted both by the government and externally tend to be more *general*, in the sense that they and their "descendants" are cited by patents in a wider variety of classes. Caution is necessary in interpreting our findings. The missions of the agencies that support research are varied (see Goldfarb, 2008 for a discussion). Research outcomes should be benchmarked to an agency's or program's implied goals, whose congruence with the Arrow-Nelson ideal will vary.

Our second central finding is that federal funding is related to the *direction* of technological change. The government funds some areas

[3] Stokes (1997) describes knowledge in a two-dimensional space: Quest for fundamental understanding, and consideration of use. Stokes partitions the knowledge space into 4 quadrants. Exclusively basic knowledge (Bohr's quadrant), knowledge that is simultaneously basic and applied (Pasteur's quadrant), knowledge that is applied but not basic (Edison's quadrant) and he leaves the final quadrant, knowledge that is neither basic nor applied unnamed. There is also a small literature that investigates the returns to R&D funding in terms of publications and scientific collaborations – though this literature does not distinguish between Pasteur's and Bohr's quadrants (Arora and Gambardella, 1996; Carter., Winkler and Biddle-Zehnder, 1987; Jacob and Lefgren, 2011). In this paper, our concern is with Pasteur's and Edison's quadrants.

[4] Patents build on prior technological solutions. However, any given patent may rely on alternative prior inventions – there is more than one way to skin a cat. Influence that is driven by tree intraconnectedness reflects knowledge with fewer technological solutions outside the tree. It's difficult to find alternative methods to skin the cat! In this sense, the citation trees of more influential patents reflect greater downstream inventive activity that is magnified by the opening of new streams of inventive activity. These new streams would have been difficult to discover absent the influential patent. In this sense patents with high influence are breakthroughs.

[5] Impact is equivalent to how the HJT measure of importance has been implemented, though not to how it was originally conceptualized. Henderson, Jaffe and Trajtenberg (1998) anticipate this problem as their measure of importance aspires to measure citations across two generations. However, their data did not allow them to follow citations more than a single generation. Corredoira and Banerjee's measure can and does accommodate any number of generations in any analysis time frame. The correlations of the measures are low. However, the correlations of the natural logs of citations and influence are much higher, 0.93 in the first 95% of the distribution. The top of the distribution - the top 5% is only correlated at 0.22. The importance of the right tail highlights the skewed nature of the distribution of returns to innovation, and indeed foreshadows the empirical strategy in this paper.

[6] Sampat (2006) found that university patents tend to cite more scientific articles than do private sector patents. Under a certain set of assumptions about the patenting decision and process, this suggests that university patents are embodiments of more basic knowledge.