Public Research Investments and Patenting: An Evidence Review

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The U.S. federal government's investments in research and development (R&D) – amounting to $150 billion a year – create knowledge for dissemination and application, ultimately to address public challenges. One way to assess these investments is through their effect on patenting. This report provides a brief review of recent scholarship on the connections between public research and patent creation and influence.

THE BOTTOM LINE:

- U.S. patents are increasingly connected, directly or indirectly, with publicly funded research.
- Patents emerging from public research may be more novel and have greater technological influence.
- Public research investments can catalyze additional innovative activity. Patenting by small firms may be particularly enhanced by public investment.

The federal government funds R&D for an array of objectives: curing disease, enhancing national security, advancing fundamental knowledge, catalyzing industrial innovation, protecting and improving agriculture, and other missions. For all, the common goal of R&D investment is to create new knowledge via discovery and invention, for its eventual dissemination and application.

Assessing knowledge output and application is not easy, but one common, if imperfect, proxy is by tracking patents, which provide property rights for new inventions.

Patent analyses typically rely on patent *citations*: references in patents or patent applications to other patents, scientific publications, research grants or other literature that can show connectivity. In recent decades, a sizable body of research has emerged assessing the relationship between public R&D funding and patenting activities. While not a perfect indicator, patents can provide broad insights into the effects and utility of public R&D. This review summarizes some current findings of this literature with a focus on high-income economies comparable to that of the United States.

Note that this review is not intended to evaluate the merits of the current patent system. It will be updated periodically with new information as appropriate.

Why patents as a metric?

If the goal is tracing knowledge flows and uses, patents can miss quite a bit of this information. Inventors or companies may choose not to patent, and different firms or even entire sectors may exhibit different patenting tendencies or strategies. Valuable knowledge generated by public research can take many forms, including *tacit* knowledge that is not written down and is instead embodied in the hiring of new Ph.D.s: as Manhattan Project Director J. Robert

Oppenheimer once told a Senate committee, "The best way to send information is to wrap it up in a person."[1]

There are several other means of disseminating knowledge of course, including peer-reviewed scientific publications, conference papers, reference manuals and other "grey literature,"[2] as well as through joint ventures or contracts. The latter may provide a resource for high-value technology acquisition but not necessarily result in a patent.[3] Different patent offices may have different requirements for applying for a patent. And this is before considering spurious relationships and "noise" within the data created by patent examiners or other third parties inserting citations and references into applications, rather than the inventors.

While patent metrics are not perfect, evidence and validation have nevertheless accumulated in recent decades to suggest they do have utility as indicators and tools for tracing knowledge flows between research and innovation.[4] This influence can be considered along a few interrelated dimensions.

First, patents can be used to explore *connections* between technological innovation and public research. While patent applications most commonly refer to other relevant patents ("prior art"), roughly one in three U.S. patents also contain references to non-patent literature.[5] The vast majority of these references are to scholarly scientific publications, which have been frequently used as a tool to trace knowledge flows between research funders, research performers and innovators. In fact, Roach and Cohen (2013) combine patent data with R&D manager surveys and find that such non-patent citations actually provide a better source than reliance on patent-to-patent linkages, though both may *underestimate* the relationship between public research and industrial innovation.[6] Regardless, connecting patents to science, and then understanding the source funding for that science, can help illuminate these connections.

While patent metrics are not perfect and should not serve as the sole indicator for evaluating research investments, they nevertheless do seem to say something useful about the innovation impacts of public research.

The nature of this relationship can be varied, according to interviews with inventors: Scientific knowledge and expertise may serve as a direct input into the inventive process or as relevant background knowledge.[7] Patent citation analysis can also add a geographic layer to our understanding, as evidence suggests the geographic proximity between knowledge creation and innovation is becoming increasingly important.[8]

Patent citation analyses can also identify particularly *important* or *novel* innovations that present something truly new or have unusually large influence on the directions of future innovations. Understanding which patents are high quality might be done by measuring how many times a given patent is cited by subsequent filings, or tracing the evolution of patent citations across new or existing technology sectors, or looking for new combinations of source knowledge and impact.

Validation studies suggest that such metrics – esoteric as they may be – do tell us something about real-world innovation. For instance, a 1991 study found that those patents highly rated by Eastman Kodak research personnel *also* tended to be highly cited in other future patents.[9] More recently, Benson and Magee (2015) explore patent citation rates and technological performance in 28 technological domains, including integrated circuits, electric motors, genome sequencing, fiber optics, solar power and others. They find a strong correlation between citation rates and rates of actual technological progress.[10] Other studies have found that award-winning innovations or otherwise "famous" inventions tend to rank highly in measures of novelty or citation impact.[11]

Combining information about funding sources with information on patent quality can further illuminate the public science/innovation connection. For instance, one key finding is that patents that look backward to original scientific sources *also* tend to be more highly cited, which, as Sorenson and Fleming write, "provides strong evidence for the notion that science accelerates innovation because its norms of openness and publication speed the diffusion of knowledge."[12]

Lastly, economists can attempt to establish the economic value of patents and citations. For instance, one noted 2005 study of patent and market valuation over a 30-year period finds that each additional patent citation increases firm market value by about 3%, and that firms with highly cited patents (concentrated in semiconductors, pharmaceuticals, computing and other high-tech sectors) also have *far* higher market value than would be expected given other company metrics.[13] Stock values of firms with highly cited, science-based patenting patterns have been shown to outperform the market as a whole.

The bottom line is that while patents are not perfect and of course should not serve as the sole indicator for evaluating research investments, they nevertheless do seem to say something useful about the innovation impacts of publicly funded research – especially in a world where any such evaluation remains difficult by any measure.

Industrial patents and public research are highly connected

Following earlier studies, a pioneering systematic analysis of the research-patent connection came in 1997 via the firm CHI Research. In their study, Narin et. al. painstakingly matched citation, scientific publication, country and institutional data from hundreds of thousands of patent references issued in the late 1980s and early 1990s, and found "massive, contemporary linkage between industrial technology and public science." Specifically, 43.9% of all scientific references in industrial patents came from U.S. public science (another 20.4% of references came from industry itself, and the remaining citations came from foreign public and private sources). There was a strong national component to these findings: U.S.-based firms were far more likely to cite U.S.-based public science than foreign science.

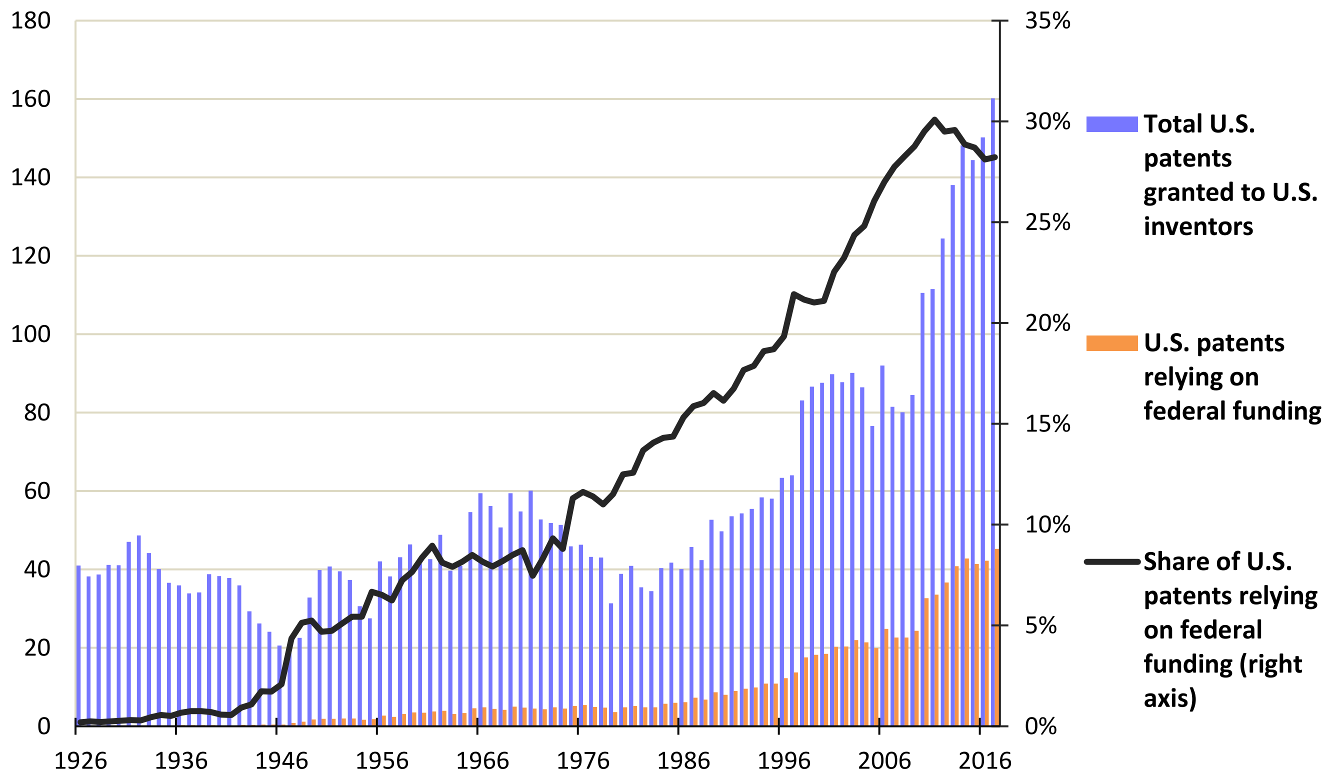
The analysis also suggested that this interaction was increasing over time, with the number of patent-paper citations roughly tripling over the preceding six-year period. Fields particularly reliant on science included drugs and medicine, chemicals, electrical components, and instrumentation. Among funders, the National Institutes of Health (NIH) was dominant in biomedical research, while the National Science Foundation (NSF), the Department of Energy and the Department of Defense were prominent in the physical sciences and engineering. Universities were major performers of this science, with additional significant contributions from industrial innovators such as Bell Labs and IBM, and from national labs.[14]

More recent research has further illuminated these connections. For instance, Li et al. (2017)[15] find that 30.8% of NIH grants are directly or indirectly connected with patents – in other words, either directly cited by a patent or leading to a scientific paper that is subsequently cited by a patent – while 5% of NIH grants are linked with a Food and Drug Administration (FDA)-approved drug. On the other hand, focusing on backward linkages from FDA-approved drugs to scientific publications, Du et al. (2019) find the vast majority of scientific references in patents in the FDA Orange Book (including privately held patents) come from public funding sources, mainly NIH.[16] Interestingly, they find little distinction between basic and applied research, suggesting a broad spectrum approach for basic and applied funding is appropriate.

In addition, a 2011 *New England Journal of Medicine* study found that 9.3% of all FDA-approved drugs between 1990 and 2007 were discovered in "public sector research institutions," a category including NIH, universities, nonprofit research institutes and teaching hospitals. Within this total, public institutions accounted for 13.3% of new molecular entities (NMEs) and 21.1% of NMEs designated for priority review, indicating chemically new drugs expected to have the highest treatment impact.[17] The authors speculate these figures represent increasing prominence of nontraditional institutions (apart from business) in downstream drug development, as opposed to simply laying the

Figure 1: U.S. Patents Relying on Federal Research

Left axis = patents (thousands). Right axis =%age reliant on federal research.



Reproduced from Fleming, Greene, Li, Marx, Yao, "Government-funded research increasingly fuels innovation," *Science,* June 21, 2019: 1139-1141 | AAAS knowledge groundwork for industrial firms as described above.

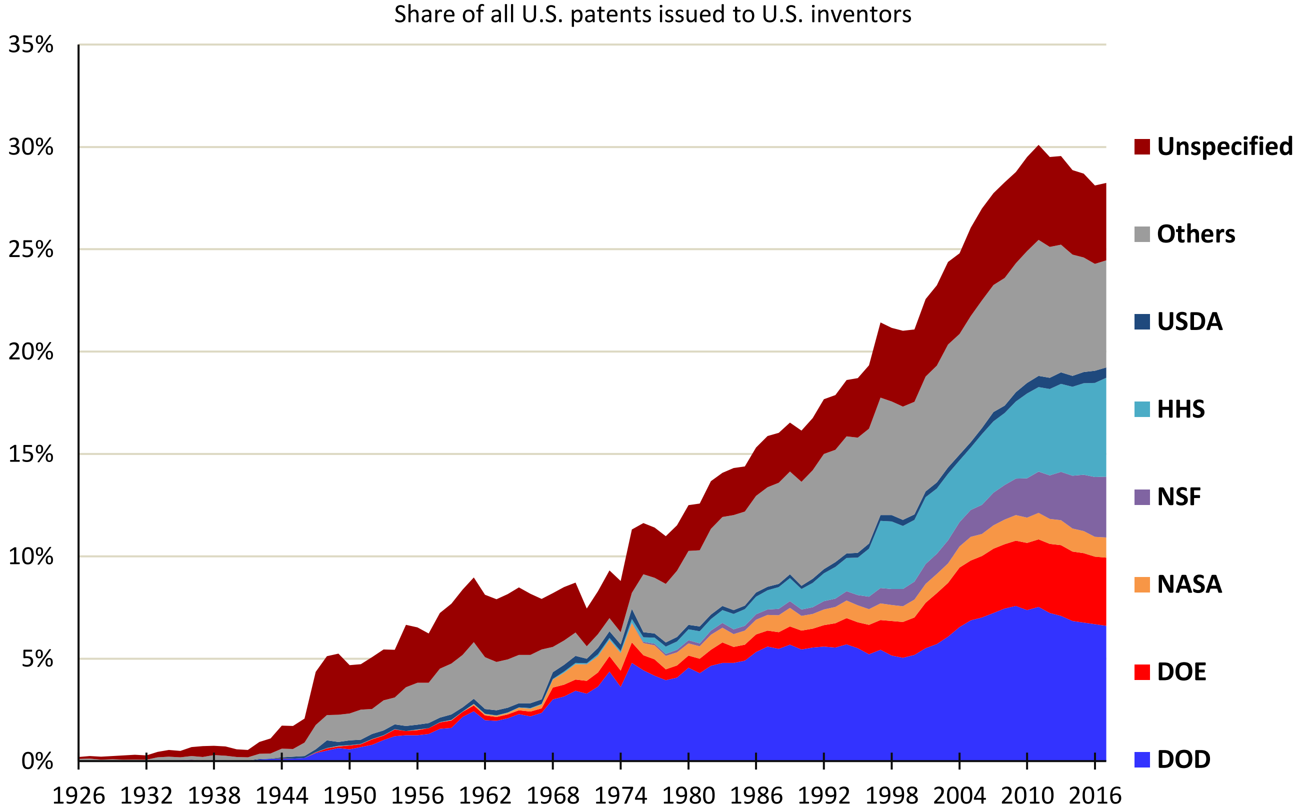
A 2019 study published in the journal *Science* (Fleming et al.) further emphasized an increasing reliance on federal research, well beyond the life sciences.[18] Assessing direct connections in millions of documents between patents, science citations and acknowledgments of government support, the authors find that up to 30% of U.S. patents granted by the Patent and Trademark Office rely on federally funded research in some fashion, directly or indirectly, representing a tripling of such connections since the 1970s (see Figure 1, previous page). The authors speculate some of this growth was driven by the 1980 Bayh-Dole Act, which facilitates patenting of government-funded research by universities and small businesses, and by shifts in federal and private research investment.

This rise cuts across several technology areas and draws on research funding from several major agencies, including the Department of Defense, Department of Health and Human Services, Department of Energy, and NSF (see Figure 2, below).

Intriguingly, the analysis also finds that corporate patents that rely on public research are cited much more often by *future* patents as prior art, suggesting they can hold an influential place in the innovation ecosystem. Patents connected to public research receive 43% more citations in subsequent patents granted to both the original inventor firms and to external competitors, suggesting, in the words of the authors, "that both the inventing

Figure 2: U.S. Patents Relying on Federal Research by Agency

Share of all U.S. patents issued to U.S. inventors



Based on data from Fleming, Greene, Li, Marx, Yao, "Government-funded research increasingly fuels innovation," *Science,* June 21, 2019: 1139-1141 | AAAS firm and its competitors find these technological trajectories more fertile."

In a similar vein, Wang and Li (2019) demonstrate the relationship between the *quality* of public science and follow-on patenting: In an analysis of nanotechnology patents, they find that high-quality, highly cited scientific papers lead to patents that are themselves more likely to be cited by future inventors.[19] More on public research, patent novelty and technological influence is below.

Some evidence suggests that public research can provide an important sourcing strategy for industrial innovation. An older survey of R&D managers in the manufacturing sector, administered in the 1990s, found that roughly one in three R&D projects drew from government or R&D labs, and that the results of public research in several disciplines – including biology and health sciences, chemistry, physics, computer science, materials, and engineering – were rated as "important" for company R&D.[20] A more recent 2005 survey of industrial R&D decision-makers suggests that access to university partnerships and a skilled R&D workforce – both heavily influenced by public research funding in the U.S. – are major factors for locating industrial facilities and research centers.[21] Recent studies of U.S. medical device firms and of Dutch biotech and cleantech firms have found that small innovative companies seek out collaboration with publicly funded research entities for a variety of reasons, including to improve firm innovation performance and learning or to pursue technology demonstration and legitimation.[22]

An important caveat when considering these connections is that there can be substantial lags between published research and patent impact, depending on the discipline or technology area: up to 20 years or more in the case of more abstract disciplines such as mathematics, for instance.

Public research can yield patents with greater novelty and influence

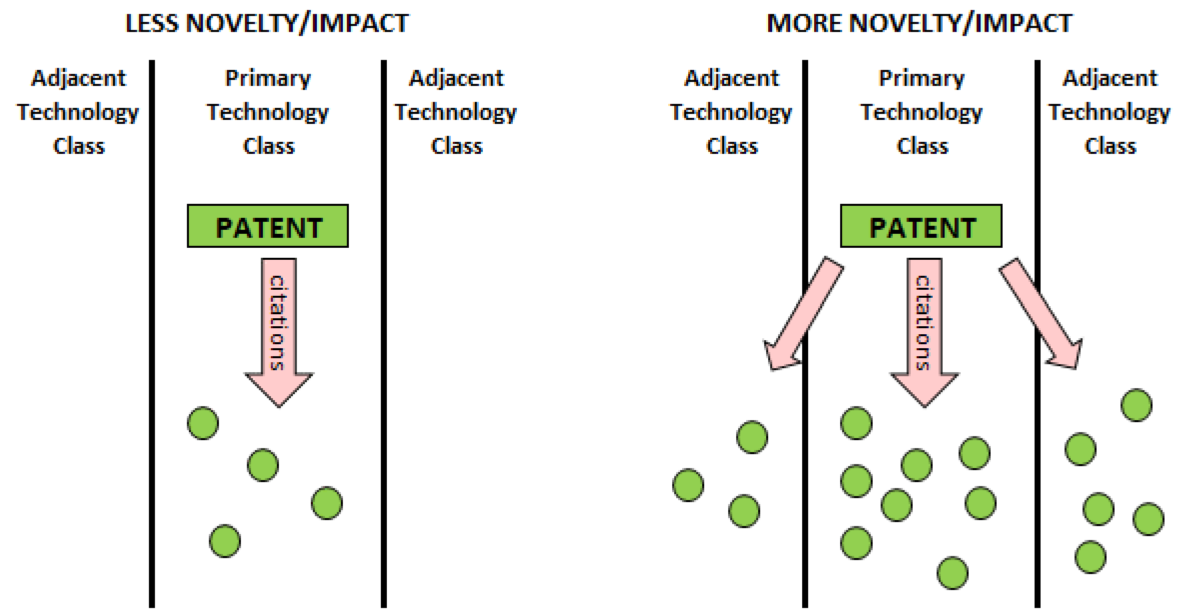
In addition to rising interconnectivity between public research and patenting, evidence has also mounted in recent decades that public research dollars can lead to *different kinds* of patent output with *different kinds of impact* than those that emerge from other funding. Specifically, when measured by future patent citations or benchmarked against other inventive activity, publicly reliant patents may provide greater novelty or open new technological territory, suggesting deep innovation impacts from public research (see box on the following page for the basic concepts of one such approach).

In a notable early study, Trajtenberg et al. (1997)[23] constructed a data set to measure the level of "basicness" in university patents versus industry patents, by tracing backward and forward patent citations. In this case, more "basic" patents are those that draw more on scientific sources, that play a seminal or influential role in future technological trajectories, that have few technological antecedents and that are relevant to a broad array of technology classes.

With that in mind, they found that compared with industry patents, university patents receive at least 30% more future patent citations (suggesting greater technology impact), influence future patents across a somewhat wider array of technology areas and draw much more heavily on scientific sources rather than previous patents as antecedents. These findings were echoed by Bacchiocchi and Montobbio (2009), who found using European Patent Office data that patents from U.S. universities and public research institutes

Measuring Novelty and Impact

One way to evaluate the impact and novelty of a given invention is to see how often or broadly the underlying patent is cited by future patents, as depicted in the illustrative concept images below. On the left, the primary patent of study is cited by fewer future patents, and these are all in the same technology class as the original patent. On the right, the main patent is cited much more often by future inventions, and it seeds other inventions in multiple new technology classes. Comparisons such as these can also be augmented by benchmarking the depth and prevalence of knowledge sources, such as the extent to which a given patent relies on other patents, the scientific literature or other sources.



are 30% more likely to be subsequently cited than U.S. corporate patents.[24]

Looking at university patents only indirectly addresses the public research question, however, to the extent that most university R&D is publicly funded. Fortunately, in the past few years, several studies have attempted to more directly answer the question of public funding and its effect on patenting. These have largely confirmed the notion that patents associated with public research can have deeper or broader impact on future technologies or introduce more science-based novelty into the innovation system. They have also emphasized the apparent importance of universities within the innovation system as a particularly effective channel for public research dollars. To review some examples:

- Funk and Owen-Smith (2017)[25] perform a network analysis of over 55,000 patents issued since 1976 to the 110 most research-intensive U.S. universities to assess whether a given patent *reinforces* the existing technological status quo (i.e., builds on current capabilities without fundamentally challenging them) or *destabilizes* it (introduces a novel invention creating a new technology path, perhaps rendering older knowledge obsolete), while also identifying institutional R&D relationships and impacts on novelty. This includes data on research grants to universities from NSF, NIH and the Department of Defense. In the words of the authors, “we found consistent evidence that while increases in federal support for academic research appear to push universities to create technologies that destabilize the status quo, increases in commercial ties are associated with university research that consolidates existing technology streams."

- In a comparative study of citations and connections between nearly 15,000 U.S. patents issued between 2006 and 2010, Schmid and Fajebe (2019) find that university- and government-assigned patents are more "general" than corporate patents: "In other words, university and government patents affect subsequent technological change in a broader range of technological sectors than corporate patents," suggesting a narrower focus for typical corporate technology efforts. The likelihood of university and government agencies producing a highly and broadly cited patent is also higher. University patent output seems particularly highly and broadly cited, suggesting that "policies that attempt to use universities as engines for advancing technological innovation may hold promise," as the authors put it.
- Turning to the renewable energy technology domain, Popp (2017) finds that both scientific articles and renewable energy patents emerging from government labs tend to be more frequently cited by future patents, while research collaborations also add value in terms of technological novelty. Crucially for policy choices, the author draws a distinction between more-mature wind technology and less-mature solar, suggesting that *private* research funding sources may provide the most value in future innovations for wind, while other institutions, including universities, may have greater impact in emerging areas such as advanced biofuels. Popp concludes, "[R]esearch not only funded but also performed by the government does appear to play an important translational role linking basic and applied research."[26]
- In Europe, the European Commission's 7th Framework Programme was partly intended to promote and fund public-private research collaborations (among other goals). In a 2018 study,[27] Szücs finds that the program had limited overall impact, but that patent impact and novelty (e.g., future citations and new patent connections between technology classes) increase with project size, firm funding, and the presence of high-quality universities in the collaboration. The author finds that "substantial returns to scale can be accrued in large research projects: not only the quality and quantity (i.e. citations and count) of patents increase, but the novelty measures increase as well."
- Veugelers and Wang (2019)[28] find some evidence to suggest that the mechanism for this elevated importance and novelty in public/university research is novel science itself: Novel scientific publications from high-risk/high-reward research – defined as publications that themselves reference new or highly unusual combinations of prior science – are more likely to be cited in novel patents. They are also more likely to be cited in other journal articles that themselves are influential in a broad array of technology fields.

In another notable study, Corredoira et al. (2018)[29] focus on over 10,000 patents issued by the U.S. Patent and Trademark Office from 2001 to 2004, including 4,311 patents either owned by government or indicating federal research support (via the "federal research statement" field on patent applications); roughly two-thirds of the sample fell into the latter category. Among extramural patents, major funding sources included the five largest R&D funding agencies: Department of Defense, Department of Energy, Department of Health and Human Services, NSF and NASA.

Patents associated with publicly funded research can have deeper or broader impacts on future technologies or introduce more science-based novelty into the innovation system.

The authors' analysis traced the "family tree" of each patent's subsequent citations to assess the breadth and depth of its technological influence. They found that patents connected with federal research tended to be more heavily cited by future patents, to be cited in a broader array of technology fields, and to appear in new technology areas in which private patenting activity was limited. The impact was particularly true for federally funded extramural research, while the effects were stronger for some agencies (such as the Department of Defense and Department of Health and Human Services) than others. Conclude the authors:

> Research results are hard to predict, and the long-term implications of results or even entire fields of research are exceptionally difficult to foresee. If science policy is fulfilling its role, we should expect to see this particularly in the long term through indirect channels. Our results suggest that for all its imperfections, U.S. science policy remains successful in supporting the long-term productivity of inventive activity … They are also in line with the notion that federally sponsored research is associated with an increased rate and broadened direction of future inventive activity. Government presence is also more likely in areas of research that would otherwise be orphaned or neglected by the private sector. In this sense, federally funded research may play an irreplaceable role in both the rate and direction of inventive activity.

The collected results described above – that patents connected to public research may be more influential on a broader array of technology classes – also suggest that public research can lead to patents with higher economic value.

Public research funding can increase patenting activity, including for small firms and startups

Public research funding seems to be increasingly interrelated with patenting, and can lead to technologies with greater novelty and impact. But does public funding lead to a net *increase* in innovation output overall, as measured by patenting activity? There are indications this is the case:

- A 2017 study of the effects of the Department of Energy's Small Business Innovation Research (SBIR) program found it has "powerful effects," specifically achieved through the earliest Phase I awards to low-carbon energy technology companies. The analysis indicates a Phase I award increases a firm's citation-weighted patenting by at least 30%, while also increasing the odds and scale of follow-on venture capital investment, positive revenues, and firm survival and exit. The author writes: "Thus, on average the early-stage grants do not crowd out private capital. Instead they enable new technologies to go forward, transforming some awardees into privately profitable investment opportunities."[30]

- The Fleming et al. (2019) analysis mentioned above also homes in on the relationship between small firms and public R&D: "Startups also depend heavily on government research, as 34.6% of the 121,765 patents assigned to venture-backed companies from 1976 to 2016 cited federally supported research; by comparison, for all corporate patents during the same time period, only 21.7% rely on federally supported research."[31] This is not unexpected, as smaller firms can have greater resource challenges, and startups may represent disruptive technological ventures spun off from academic research as described above.

- NIH funding has been found to have additive effects vis-a-vis patents. For instance, using 25 years of NIH grant data coupled with U.S. patenting and publications information, Azoulay et al. (2019) find that each additional $10 million in NIH funding for a particular disease research area generates an additional 2.7 industrial patents in that area, without crowding out industrial research investment in *other* disease areas.[32] In other research, Toole (2012) finds that a 1% increase in basic NIH research is associated with a 1.8% increase in the number of industry applications to the FDA for NMEs.[33] Relatedly, increased NIH funding has also been associated with creation of new biotech firms.[34]

- There is substantial evidence that public R&D investments can enhance patenting in the low-carbon energy space. Doblinger (2019) finds a sharp increase in patenting by clean technology startups for those firms that engaged in technology development partnerships with public labs.[35] Other multinational studies have found net-positive increases in patenting from public R&D support in the wind power and advanced biofuels sectors.[36] Palage (2019) finds evidence that steady public R&D coupled with technology-pull policies (specifically, feed-in tariffs) may maximize patenting activities in solar photovoltaics.[37]

Advantage can be had when research subsidies are able to leverage research networks or clusters integrating public, private and academic institutions. Small firms may be particularly fruitful targets for leveraging public research funding or results.

- Vestal and Danneels (2018) add a geographic component. Focusing on U.S. nanotechnology firms and clusters, they find that the local presence of public research organizations, including national labs, government labs, universities, research institutes and other such entities, is associated with increased firm patenting as well as novelty of said patents, along with local knowledge sourcing and collaboration. Essentially, the greater the public investment in nanotechnology research, the more it enhances the inventive productivity of related firms.

- Similar findings have been found in Europe. In a study of German firms in the

1990s, Czarnitzki and Hussinger (2018) find public R&D subsidies increase both patenting and future patent citations. This effect is similar for private R&D, and suggests public R&D does increase technological innovation by a similar magnitude as private investment.[38] More recent analyses have focused on German biotech firms and public R&D grants,[39] and on European Union green technology research networks and patenting.[40] Both cases have again shown a net-positive impact of public research dollars and performers on inventive performance.

Other results generally run in this positive direction, but they are not uniform. For instance, one recent study of public support (including both R&D subsidies and tax credits) of small and midsize Italian manufacturers finds that public policy succeeded in incenting additional R&D investment from industry, but did not lead to any increases in propensity to patent.[41] It's difficult to assess why there may be varying results in terms of public investments' impacts on patenting. One factor may be the idea of "absorptive capacity" – a firm's own in-house know-how, research activities and skill base – which has been shown to be critical for companies to leverage the knowledge produced by public research. For instance, a 2009 study found that biotech and pharmaceutical firms that invested more in their own internal research and contributed to the scientific literature were in a better position to take advantage of university research collaborations, yielding faster and higher-impact technology patents.[42] Conversely, if firms do *not* have sufficient absorptive capacity, it can hamper the benefits of such interaction.[43]

As such, the patenting effects of public research may be greatest where industrial capacity to absorb research results is highest, including in advanced industries requiring substantial technical know-how such as biotech, advanced materials, aerospace and the like. For perspective, the R&D intensity of U.S. firms (referring to business R&D investments as a share of gross domestic product, primarily for development) was eighth highest in the world in 2017 according to Organisation for Economic Co-operation and Development (OECD) data, behind Korea, Taiwan, Japan, Switzerland, Sweden, Germany and Denmark.[44] Improving this investment intensity may offer a path to improved production of intellectual property.

It seems advantage can also be had when research subsidies are able to leverage research networks or clusters integrating public, private and academic institutions. As the cases mentioned above indicate, small firms may be particularly fruitful targets for leveraging public research funding or results into net patenting increases, as one would expect small firms to have the greatest financial constraints on R&D and thus see the greatest marginal benefit.

Conclusion

Patents can tell us something useful about the creation and dissemination of knowledge and ideas, even if they are not the perfect metric. As covered above, the evidence has grown substantially in recent years that public research is a significant factor in patent creation. The influence of public research falls along three dimensions.

First, public research appears to be *increasingly connected* with patenting, with as many as 30% of all patents tracing directly or indirectly to public research, including approximately one-fifth of all corporate patents. This is a marked increase from the past and includes several major federal research funders such as the Department of

Defense, NIH, NSF and others. The relationship between public research and private innovation is perhaps most clearly demonstrated in pharmaceuticals, but it also turns up in chemicals, computer science, and other sectors and disciplines.

Second, patents reliant on public research funding (often channeled through universities) seem to be qualitatively different from patents that do not, offering *greater novelty and technological impact*. This means that public research patents tend to be more highly cited by future patents, which suggests higher economic value. Public research patents also tend to influence subsequent inventions in a broader array of technology fields, including those neglected by industrial research, and can blaze new trails into entirely new sectors.

Lastly, public research can *increase the rate of patenting*. Again, multiple large federal research funders seem to play a role as catalysts. This effect can be achieved through direct funding as well as through alliances and partnerships. The effect may be particularly important for small firms operating in high-tech sectors such as nanotech, biotech and low-carbon energy tech.

These effects seem to be broadly relevant for federal research programs in general, applying across disciplines and performers. In time, additional studies may shed more light on the relative patenting influence of different disciplines or funding modalities, which in turn may offer more precise insights for decision-makers.

ADDENDUM

The sources cited in the preceding review were assembled using a mix of Web of Science and Google Scholar keyword searches coupled with a review of backward and forward citations.

Gilda Barabino, Joanne Carney, Kathie Olsen and Kate Stoll served as gracious reviewers of this report. Any errors and omissions are the author's alone.

ABOUT US

Since 1976, the AAAS R&D Budget and Policy Program has served as an independent source of data and analysis on federal support for research and development.

[1] Before the Senate Committee on Military Affairs, October 17, 1945.

[2] See for instance Anderson, G.W. & Breitzman, A. (2017) Identifying NIST impacts on patenting: A novel data set and potential uses. *Journal of Research of the NIST 122*. https://doi.org/10.6028/jres.122.013

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