The impact of public R&D investments on patenting activity: technology transfer at the U.S. Environmental Protection Agency

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Abstract:

This paper presents estimates of the impact of public R&D on patenting activity at the U.S. Environmental Protection Agency (EPA). Using a time series of public sector agency data, we estimate the per-capita R&D elasticity of new patent applications using a knowledge production function framework model that is an expanded version of what other scholars have used with private sector data. New patent applications are an important step in the technology transfer activities of a federal agency. We estimate this elasticity to be about 2.0. This elasticity value represents an initial estimate of the impact of EPA's R&D investments on its technology transfer activity.

Keywords: R&D | patents | technology transfer | knowledge production function | Environmental Protection Agency

Article:

1. Introduction

Productivity growth began to decline throughout the U.S. industrial sector in the early 1970s, and that decline became more pronounced in the late 1970s (Link and Siegel 2003; Leyden and Link 2015). There were a number of policy responses to this productivity slowdown, and the seeds for several of them were set forth in President Jimmy Carter's 1979 Domestic Policy Review (Carter 1979). Among areas of emphasis was the transfer of federally funded technology to the private sector:

> Often, the information that underlies a technological advance is not known to companies capable of commercially developing that advance. I am therefore taking several actions to ease and encourage the flow of technical knowledge and information. These actions include establishing the Center for the Utilization of Federal Technology at the National Technical Information Service to improve the transfer of knowledge from Federal laboratories; and, through the State and Commerce Departments, increasing the availability of technical information developed in foreign countries.

The U.S. Congress responded to this charge in several ways. In October 1980, Congress passed the Stevenson-Wydler Technology Innovation Act of 1980 (Public Law 96-480). This act states that Congress finds and declares:

> Technology and industrial innovation are central to the economic, environmental, and social well-being of citizens of the United States. Technology and industrial innovation offer an improved standard of living, increased public and private sector productivity, creation of new industries and employment opportunities, improved public services and enhanced competitiveness of United States products in world markets. Many new discoveries and advances in science occur in universities and Federal laboratories, while the application of this new knowledge to commercial and useful public purposes depends largely upon actions by business and labor. Cooperation among academia, Federal laboratories, labor, and industry, in such forms as technology transfer, personnel exchange, joint research projects, and others, should be renewed, expanded, and strengthened. … It is the continuing responsibility of the Federal Government to ensure the full use of the results of the Nation's Federal investment in research and development. To this end the Federal Government shall strive where appropriate to transfer federally owned or originated technology to State and local governments and to the private sector.

To enhance the technology transfer mission of federal laboratories, Congress amended the Stevenson-Wydler Act in October 1986 with the passage of the Federal Technology Transfer Act (FTTA) of 1986 (Public Law 99-502). This new act also established the Federal Laboratory Consortium (FLC) for Technology Transfer, and the National Bureau of Standards, which later became the National Institute of Standards and Technology (NIST), acted as the host agency for the FLC. The FTTA provides an additional incentive for federal agency scientists and researchers to be proactive in the identification and transfer of their technologies by requiring that royalties and income received from the licensing of patented technologies be retained by the federal agency and shared with its inventor(s). Finally, the FTTA facilitated technology transfer by permitting the agencies to enter into cooperative research and development agreements (CRADAs) with public and private organizations.[1]

Technology transfer from federal agencies and their laboratories has traditionally been a bipartisan issue in the United States. Recently, President Barack Obama issued, on October 28, 2011, 'Presidential Memorandum: Accelerating Technology Transfer and Commercialization of Federal Research in Support of High-Growth Businesses' (Obama 2011). The President's Memorandum specifically emphasized the relationship between technology transfer, innovation, and economic growth:

> Innovation fuels economic growth, the creation of new industries, companies, jobs, products and services, and the global competitiveness of U.S. industries. One driver of successful innovation is technology transfer, in which the private sector adapts Federal research for use in the marketplace. … I direct that [Federal laboratories] establish goals and measure performance, streamline administrative processes, and facilitate local and regional partnerships in order to accelerate technology transfer and support private sector commercialization.

Technology transfer from federal agencies is also a point of emphasis for President Donald Trump. In the spirit of public accountability, the Trump Administration pointed out (Trump, Undated, 48):[2]

> The Federal Government invests approximately $150 billion annually in research and development (R&D) conducted at Federal laboratories, universities, and other research organizations. For America to maintain its position as the leader in global innovation, bring products to market more quickly, grow the economy, and maintain a strong national security innovation base, it is essential to optimize technology transfer and support programs to increase the return on investment (ROI) from federally funded R&D.

Traditionally defined technology transfer from federal agencies has focused on patents, licenses, and CRADAs. Surprisingly, there are few academic studies that examine any of these dimensions of technology transfer from federal agencies. The few that do are summarized in Section 2. We suggest that a reason for this paucity of scholarship is that access to technology transfer data from federal agencies, much less from their research laboratories, is limited.

Some scholars have studied the R&D-to-patenting relationship using private sector firm data (discussed below), but little is known about the economic impact of publicly funded R&D on public sector patenting activity. The absence of such information is one factor that motivated NIST and the White House Office of Science and Technology Policy to sponsor recently the Unleashing American Innovation initiative.[3]

In this paper, we build on the framework used by scholars who have studied the R&D-to-patenting relationship among private sector firms to focus on patenting activity at the U.S. Environmental Protection Agency (EPA). Patenting activity at the EPA, and its developed technologies, have not been widely studied. But, in an era of global environmental emphasis, a study of EPA-developed technology and its transfer to the private sector will likely be of broad-based interest and importance because of the subject matter associated with EPA research.

For context, we briefly discuss the history of the EPA in Section 3. Ours is not a paper related specifically to public sector support of environmental research; rather, it is a paper illustrating the estimation of a public sector knowledge production function that uses an EPA set of data as we discuss below.

In Section 4, we present and discuss available time series data on several technology transfer metrics from the EPA. Our discussion of technology transfer metrics from EPA, albeit a single agency, represents to the best of our knowledge the first research effort to illustrate a detailed time pattern in such metrics. Our choice to illustrate the estimation of a public sector knowledge production function with EPA data is motivatived by the relative length of the time series of information available from EPA and by the inclusion of information on new invention disclosures, which are a necessary first step within a firm or federal agency for a new patent application.

In Section 5, we analyze these EPA data econometrically with an eye toward quantifying aspects of the patenting impacts traceable to EPA's R&D investments. Our econometric specification of a knowledge production function framework is more complete than the model used by other researchers who examined the R&D-to-patent application relationship within a knowledge production framework among private sector firms. Our ability to expand the knowledge production function framework to include new invention disclosures is due to the richness of the EPA data. We find empirically that the per-capita R&D elasticity of new patent applications is about 2.0. Finally, we conclude the paper in Section 6 with summary remarks and a discussion of the implication of our elasticity estimate as well as possible future research related to technology transfer from federal agencies/laboratories.

2. Academic literature on technology transfer

In the late 1990s and early 2000s, a series of articles began to bring together fragmented and disaggregated datasets related to federal agency technology transfer activities. These studies were limited to specific agencies that were willing to share information with researchers, as our review of the U.S. federal agency/laboratory technology transfer literature below illustrates. Thus, our paper is arguably one of the more complete analyses of technology transfer through patent applications from a federal agency/laboratory.

Regarding the literature, Jaffe, Fogarty, and Banks (1998) and Jaffe and Lerner (2001) undertook a significant data collection effort for their empirical study of patenting behavior at NASA and the Department of Energy (DOE). Their two papers concluded that the federal policy changes in the 1980s were followed by increased patenting activity in both agencies. Jaffe and Lerner (2001) found that as a result of this increase, federal laboratories reached parity with universities in terms of patents per R&D dollar without an overall decline in patent quality. Using NASA data, Jaffe, Fogarty, and Banks (1998) established that patent citations are a reasonable, but still noisy, measure of technology spillovers. Furthermore, geographic proximity between a firm and the laboratory increases knowledge spillovers as measured by citations.

Link, Siegel, and Van Fleet (2011) is a longitudinal study of overall patenting activity at two federal laboratories: NIST and Sandia National Laboratories (combined). The authors examined the trend in patenting in these laboratories in response to the Stevenson-Wydler Act and the Federal Technology Transfer Act, and they inferred from the time series that the latter act had the greater impact on increasing patenting activity.

Stevens et al. (2011) employed a novel approach for exploring the social value of intramural research that had been transferred to private-sector partners. Specifically, they investigated the degree to which successful drug discovery and development projects were derived from public-sector research. These authors did not identify the mechanism through which public sector research was transferred to the private sector, but given that they attributed technology to public sector research institutions based on patents, it is likely that the method of transfer was a license negotiated between the public sector and the firm. They found that medical technologies derived from public sector research (likely through licenses) are expected to have a significant therapeutic effect; more than half are used in treating cancer or infectious diseases.

Finally, Chen, Link, and Oliver (2018) used data on CRADA activity at NIST to explore several research questions: Did the Federal Technology Transfer Act have an impact on CRADA activity at NIST? Is CRADA activity at NIST a cyclical phenomenon? And, at what frequency do private sector establishments engage in CRADA activity with NIST? The authors characterize this last research question as an exploratory test of the relationship between firm size and the propensity to engage in a CRADA. The authors found suggestive evidence that the FTTA began to influence NIST's CRADA activity within two to three years after its passage, and that CRADA activity moves with the business cycle. The authors also found that most establishments that were engaged in CRADA activity were engaged only once; only the larger establishments continued to engage over time in CRADAs with NIST.[4]

The extant literature, as summarized above, is limited in its scope of emphasis and level of analysis on technology transfer metrics arguably due to limitations on relevant data. We contribute to the literature by overcoming these shortcoming by not only investigating a time series of data on patent activity from one U.S. agency, the EPA, but also by acknowledging conceptually and empirically the role of invention disclosures in the patenting process.

3. A brief history of the EPA

The establishment of the EPA resulted from the conflux of a number of events that affected society. These events included the widespread use of pesticides as the U.S. agrarian economy grew in the post-World War II period, which contributed to the degradation of the environment. Emissions from industrial manufacturing growth and the increase in use of automobiles were polluting the air. Destructive chemicals and toxic nuclear waste were being dumped daily into lakes, streams, and rivers; discarded pesticides used to produce America's food were killing wildlife and becoming imbedded in the food chain.

Historically, state and local governments had jurisdiction for environmental protection; however, most states did little to protect the environment. Many individuals and businesses, through their ignorance, believed the environment was an inexhaustible resource that could be exploited without repercussion (Andrews 2011). Some observers contend that the publication of Rachel Carson's Silent Spring in 1962 was the inspiration that planted the seed for the national environmental movement that began that year and extended into the 1970s (EPA 2018). Carson, an avid birdwatcher, was concerned that the continued heavy use of pesticides would kill all the birds and with no birds to sing, every spring would become silent. She also connected this likelihood to the results of the defoliation tactics used by the United States in the Vietnam War (Andrews 2011). Citizens became alarmed at the possibility of hidden poisons coming from the environment they once saw as being indestructible. The American people began to realize that there are repercussions to the mistreatment of the environment, and the media played an important role in keeping the public up-to-date on the latest environmental disasters.

President Richard Nixon's administration perceived that an emphasis on environmental issues would provide an opportunity to draw attention away from the unpopular Vietnam War. In December 1969, he appointed a White House committee lead by Mr. Roy Ash, known as the Ash Council, to determine whether a separate environmental institution should be established. At the same time, Congress sent the National Environmental Policy Act (NEPA, Public Law 91-190) to President Nixon for his signature. The purposes of NEPA are:

> To declare a national policy which will encourage productive and enjoyable harmony between man and his environment; to promote efforts which will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man; to enrich the understanding of the ecological systems and natural resources important to the Nation; and to establish a Council on Environmental Quality.

The Council on Environmental Quality (CEQ) was created to advise the President on environmental matters and to review Environmental Impact Statements submitted by all federal agencies planning projects with major environmental impact (Lewis 1985).

President Nixon signed NEPA into law on New Year's Day 1970. During this event, he declared the 1970s to be the decade of the environment. Later that month, President Nixon emphasized environmental issues in his State of the Union address. He then submitted to Congress in February of that year a 37-point environmental action plan giving special emphasis to strengthening federal programs to clean-up air and water pollution (Lewis 1985).

In April 1970, the public's concern for the environment culminated with the first Earth Day celebration, the largest demonstrations since the celebration of the victory to end World War II (EPA 2018). A week later, the Ash Council submitted its report and recommendations to the President. The report strongly favored an independent agency to coordinate the administration's environmental efforts. The council favored an independent agency because it would not require Congressional approval and could be established through a Presidential Reorganization Plan to consolidate existing executive programs into one new agency. The new agency would absorb the CEQ and have the same mission but with an additional responsibility to establish and enforce environmental standards.

After President Nixon issued Reorganization Plan No. 3 in July 1970, which officially established the EPA on December 2, 1970, he chose his Assistant Attorney General, William D. Ruckelshaus, as the EPA's first Administrator.

The EPA began as a so-called holding company housing existing programs from other executive departments and agencies with no legislative power to set policies among the various programs. Bipartisan Congressional acts gave teeth to the new agency by giving it a mandate and powers to reduce air, water, and land pollution and to protect the public from harmful pesticides and other manmade chemicals (EPA 2018).

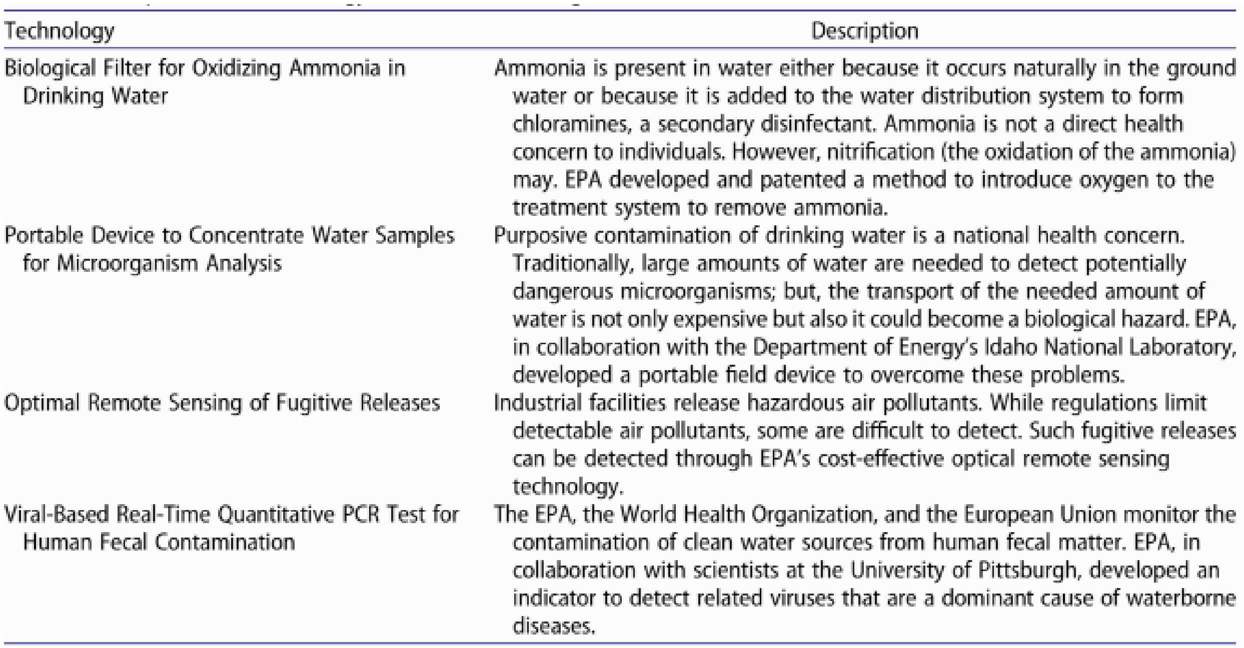
Several pieces of legislation directly involved the EPA and thus elevated its national visibility. Two of these legislations include the Clean Air Act of 1970 (Public Law 91-604),5 which has the purpose of, among other things, protecting the Nation's air resources to promote the public health and welfare and the productive capacity of its population; and the Clean Water Act of 1972 (Public Law 92-500),6 which has the objective of restoring and maintaining the chemical, physical, and biological integrity of the Nation's waters.[7]

4. Technology transfer data from the EPA

As we noted in Section 1, The Federal Technology Transfer Act required that the FLC report to the President and to Congress the technology transfer efforts of federal agencies. President Ronald Reagan's April 10, 1987 Executive Order 12591 formalized this reporting. Since 1987, the then Office of Technology Policy within the Technology Administration of the Department of Commerce submitted to Congress biannual reports as required. Currently, these reports are prepared annually and submitted to the President and to Congress through the Technology Partnership Office at NIST.[8]

Each report contains an agency's self-reported examples of successful technology transfers. EPA also publicizes it patented technologies that are available for licensing. Several such technologies are briefly described in Table 1. The point of these descriptions is not to emphasize the environmental nature of our analysis. On the contrary. Our use of an EPA set of data is motivated by its richness to illustrate an estimate of a public sector knowledge production function. The descriptions in Table 1, much like the information in Section 3, are intended to provide context for understanding the nature of the data.

Table 1. Examples of EPA technology available for licensing.



Technology	Description
Biological Filter for Oxidizing Ammonia in Drinking Water	Ammonia is present in water either because it occurs naturally in the ground water or because it is added to the water distribution system to form chloramines, a secondary disinfectant. Ammonia is not a direct health concern to individuals. However, nitrification (the oxidation of the ammonia) may. EPA developed and patented a method to introduce oxygen to the treatment system to remove ammonia.
Portable Device to Concentrate Water Samples for Microorganism Analysis	Purposive contamination of drinking water is a national health concern. Traditionally, large amounts of water are needed to detect potentially dangerous microorganisms; but, the transport of the needed amount of water is not only expensive but also it could become a biological hazard. EPA, in collaboration with the Department of Energy's Idaho National Laboratory, developed a portable field device to overcome these problems.
Optimal Remote Sensing of Fugitive Releases	Industrial facilities release hazardous air pollutants. While regulations limit detectable air pollutants, some are difficult to detect. Such fugitive releases can be detected through EPA's cost-effective optical remote sensing technology.
Viral-Based Real-Time Quantitative PCR Test for Human Fecal Contamination	The EPA, the World Health Organization, and the European Union monitor the contamination of clean water sources from human fecal matter. EPA, in collaboration with scientists at the University of Pittsburgh, developed an indicator to detect related viruses that are a dominant cause of waterborne diseases.

Source: http://www2.epa.gov/ftta

The technology transfer data analyzed in this paper come from the annual reports prepared by the Technology Partnership Office.9 Figure 1 shows EPA's new invention disclosures10 and new patent applications by year for fiscal years (FY) 1987 through 2015. Figure 2 shows EPA's R&D expenditures and the total number of EPA employees over the same time period.

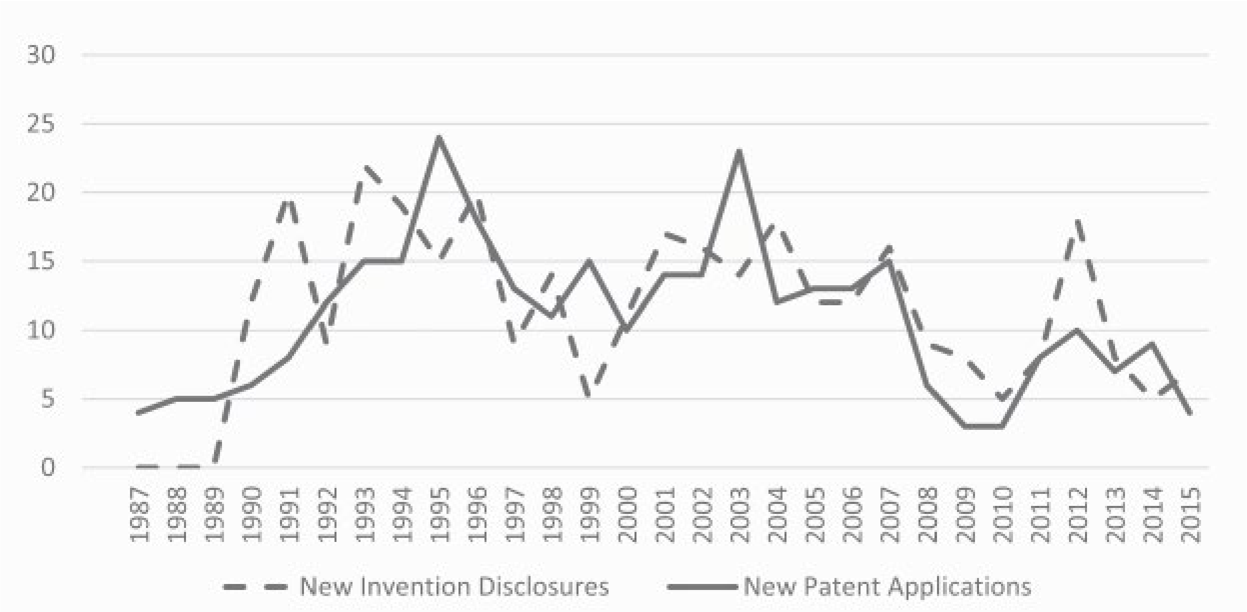


Figure 1. EPA invention disclosures and new patent applications, FY 1978- FY 2015. Source: https://www.nist.gov/tpo/federal-laboratory-interagency-technology-transfer-summary-reports

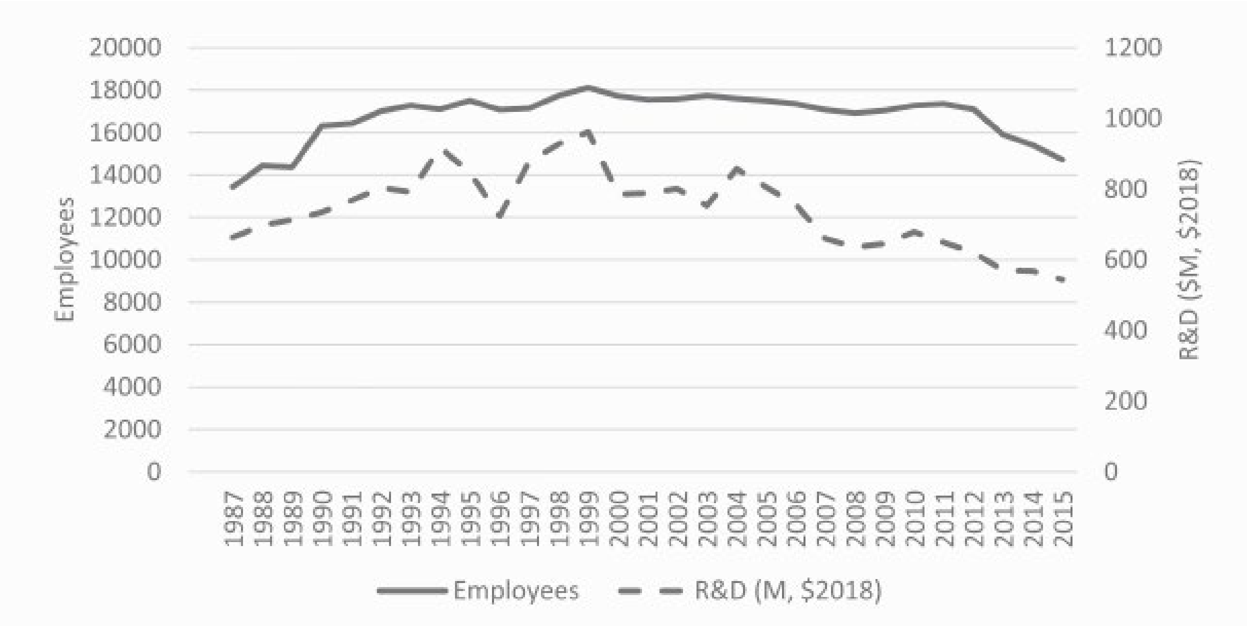


Figure 2. EPA employees and R&D expenditures, FY 1978- FY 2015. Sources: https://www.aaas.org/page.historical-trends-federal-rd#Agency; https://epa.gov/planandbudget/budget

From Figure 1, new patent applications have been declining since the turn of the century, with an increase in that decline beginning prior to the Great Recession. Disclosures have generally followed that same pattern with the exception of a spike in FY 2011 and FY 2012. Figure 2 shows that the decline in R&D expenditures is similar to the decline in new patent applications, with a slight decline in employment coming somewhat later.

5. EPA's knowledge production function: empirical estimates

There is a rich literature that has examined the R&D-to-patenting relationship among private sector firms. As mentioned above, we rely on the knowledge production function framework from this literature to examine the R&D-to-patenting relationship at the EPA. To the best of our knowledge, ours is the first paper to estimate a knowledge production function using public sector data.

Much of the literature related to patenting in private sector firms was recently reviewed by Hall and Harhoff (2012). A portion of that literature is generally referenced as being under the rubric of an estimation of a knowledge production function (Griliches 1979). The logic is that R&D is an investment into the creation of new knowledge, and within an organization the amount of new knowledge can be measured in terms of the number of new patent applications.[11]

The general form for an estimable knowledge production function is, following Hall and Ziedonis (2001) and Czarnitzki, Kraft, and Thorwarth (2009):

$$PatApp = A\,RD^{\alpha}L^{\beta} \qquad (1)$$

where PatApp is the count of new patent applications, A is a constant or disembodied shift factor, RD represents R&D investments, L represent the number of employees, and α and β measure the contribution of each input to the production of patent applications. However, there is a second independent variable that affects new patents that previous scholars have omitted from their analyses, namely new invention disclosures. In fact, new invention disclosures are a necessary first step within a firm or federal agency for a new patent application. Thus, we expand equation (1) to be:

$$PatApp = A\,RD^{\alpha}L^{\beta}D^{\gamma} \tag{2}$$

Equation (2) can be rewritten in two ways. Taking the natural logarithm in equation (2) yields:

$$\log(PatApp) = \log(\mathrm{A}) + (\alpha+\beta+\gamma)\log(L) + \alpha\,\log(RD/L) + \gamma\,\log(D/L) \tag{3}$$

Alternatively, equation (2) itself can be rewritten as:

$$PatApp = \exp(\log(\mathrm{A}) + (\alpha+\beta+\gamma)\log(L) + \alpha\,\log(RD/L) + \gamma\,\log(D/L)) \tag{4}$$

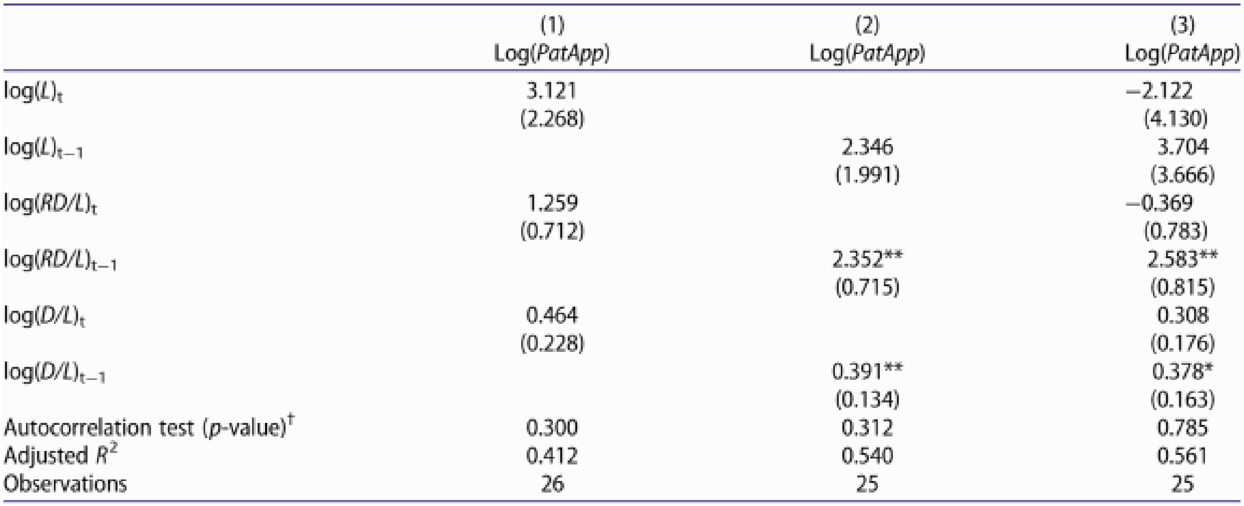
Not only do equations (3) and (4) represent a framework for the first inquiry into the estimation of a public sector knowledge production function, our use of EPA data allows us to expand the specification of the model in equation (2) to include new invention disclosures, D.[12]

Equation (3) can be estimated by an OLS regression, using those observations for which the logarithms are well-defined. Equation (4) can be estimated by a Poisson or negative binominal regression. These regression models conform to the relevant literature on knowledge production functions.13 The results from estimating equations (3) and (4), using the data from which Figures 1 and 2 were prepared, are reported in Tables 2 through 4.

The regression results in column (1) of each table are from a specification using contemporaneous values of the independent variables. Disclosures are a significant covariate with new patent applications in the Poisson and negative binominal models, but not in the linear model. The regression results in column (2) of each table explore the predictive power of a one-year lag of the independent variables. Uniformly, the R&D and disclosure variables are significant. The estimated coefficients on log (RD/L)t-1 measure the per-capita R&D elasticity of new patent applications. From the linear model, a 10 percent increase in per-capita R&D in the previous year is associated with a 23.5 percent increase in new patent applications in the current year. The estimated elasticities from the Poisson and negative binominal models are slightly lower.

According to the estimated coefficients of log (D/L)t-1, a 10 percent increase in per-capita disclosures of new inventions in the previous year is associated with a 3.9 to 4.1 percent increase in the number of new patent applications. Comparing the values of the adjusted R-squared (Table 1) and the log-likelihood (Tables 2 and 3) between the first and second columns, it is clear that lagged values of R&D per-capita and disclosures per-capita are much better predictors than contemporaneous values, in terms of model fit. The regression results in column (3) of each table include both contemporaneous and one-year lagged independent variables to account for the time needed to engage in research. Again, the one-year lagged R&D and disclosure variables are significant, and the magnitude of the per-capita R&D elasticities is slightly larger compared to the estimates in columns (2). While the model fit improves when both contemporaneous and lagged explanatory variables are included, the estimated coefficients of contemporaneous R&D per-capita are all insignificant.

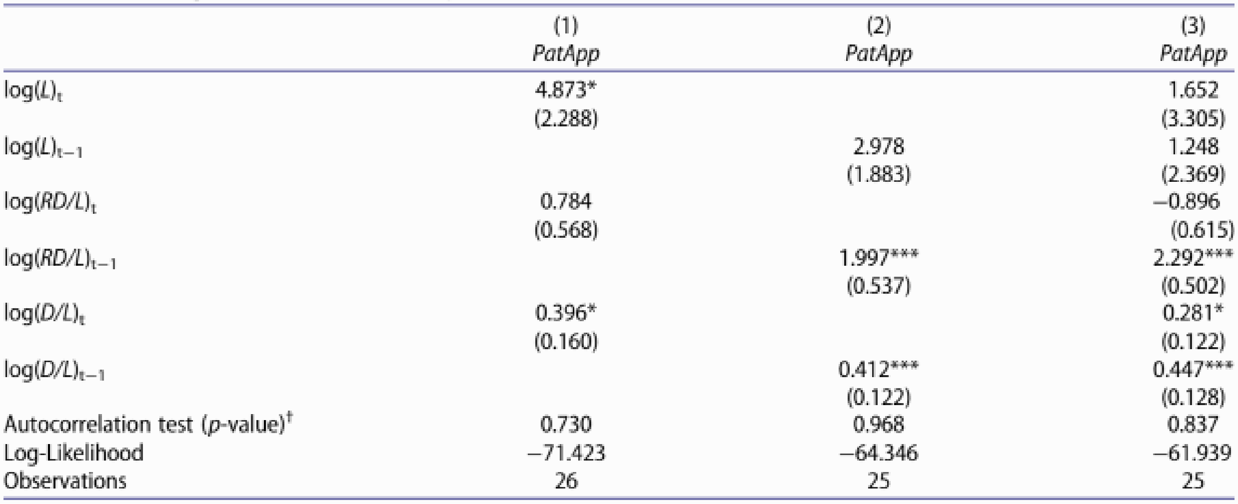
Table 2. OLS regression estimates from equation (3).



	(1) Log(*PatApp*)	(2) Log(*PatApp*)	(3) Log(*PatApp*)
$\log(L)_t$	3.121		−2.122
	(2.268)		(4.130)
$\log(L)_{t-1}$		2.346	3.704
		(1.991)	(3.666)
$\log(RD/L)_t$	1.259		−0.369
	(0.712)		(0.783)
$\log(RD/L)_{t-1}$		2.352**	2.583**
		(0.715)	(0.815)
$\log(D/L)_t$	0.464		0.308
	(0.228)		(0.176)
$\log(D/L)_{t-1}$		0.391**	0.378*
		(0.134)	(0.163)
Autocorrelation test (p-value)†	0.300	0.312	0.785
Adjusted R^2	0.412	0.540	0.561
Observations	26	25	25

Robust standard errors in parentheses.
*p< 0.05, **p< 0.01, ***p< 0.001.
† Two-sidedp-values for the null hypothesis of no autocorrelation. The test is a Lagrange multiplier test described in Godfrey (1988).

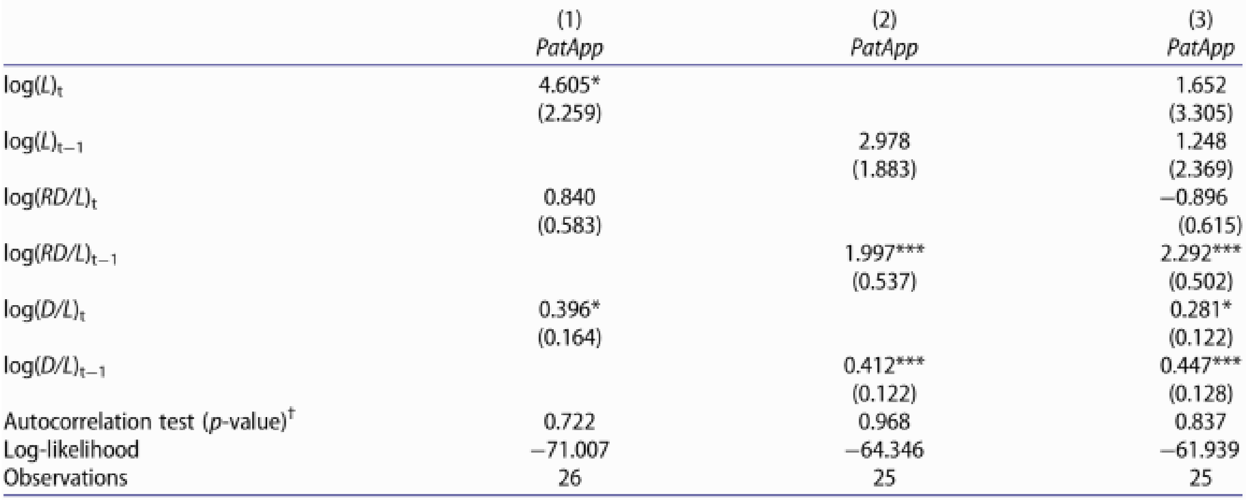
Table 3. Poisson regression estimates from equation (4).



	(1) *PatApp*	(2) *PatApp*	(3) *PatApp*
$\log(L)_t$	4.873*		1.652
	(2.288)		(3.305)
$\log(L)_{t-1}$		2.978	1.248
		(1.883)	(2.369)
$\log(RD/L)_t$	0.784		−0.896
	(0.568)		(0.615)
$\log(RD/L)_{t-1}$		1.997***	2.292***
		(0.537)	(0.502)
$\log(D/L)_t$	0.396*		0.281*
	(0.160)		(0.122)
$\log(D/L)_{t-1}$		0.412***	0.447***
		(0.122)	(0.128)
Autocorrelation test (p-value)†	0.730	0.968	0.837
Log-Likelihood	−71.423	−64.346	−61.939
Observations	26	25	25

Robust standard errors in parentheses.
*p< 0.05, **p< 0.01, ***p< 0.001.
† Two-sidedp-values for the null hypothesis of no autocorrelation. The test is a Lagrange multiplier test described in White (1992)

Table 4. Negative binominal regression estimates from equation (4).



	(1) *PatApp*	(2) *PatApp*	(3) *PatApp*
$\log(L)_t$	4.605*		1.652
	(2.259)		(3.305)
$\log(L)_{t-1}$		2.978	1.248
		(1.883)	(2.369)
$\log(RD/L)_t$	0.840		−0.896
	(0.583)		(0.615)
$\log(RD/L)_{t-1}$		1.997***	2.292***
		(0.537)	(0.502)
$\log(D/L)_t$	0.396*		0.281*
	(0.164)		(0.122)
$\log(D/L)_{t-1}$		0.412***	0.447***
		(0.122)	(0.128)
Autocorrelation test (*p*-value)†	0.722	0.968	0.837
Log-likelihood	−71.007	−64.346	−61.939
Observations	26	25	25

Robust standard errors in parentheses.
*p< 0.05, **p< 0.01, ***p< 0.001.
† Two-sidedp-values for the null hypothesis of no autocorrelation. The test is a Lagrange multiplier test described in White (1992)

Because our data are time series, we also investigate the possibility of autocorrelation in the regression errors. In linear models, autocorrelation adversely affects the efficiency of an OLS estimator whereas in nonlinear models, such as the Poisson and negative binomial regressions, it leads to biased estimates. In the linear specifications, we used the least squares residuals and calculated a Lagrange multiplier statistic to the null hypothesis of zero autocorrelation.14 For the nonlinear specifications, we used a modification of this test, described in White (1992). Tables 2 through 4 show the p-values of these tests under the null hypothesis of zero autocorrelation. With a minimum p-value of 0.30, none of our model specifications provide evidence of the presence of autocorrelation in the errors.

6. Conclusions

This paper presents estimates of the impact of R&D on patent applications in one U.S. federal agency derived from what is arguably the first estimation of a public sector knowledge production function. Our findings, using rich time series data from the EPA on new invention disclosures as well as new patent applications, are that R&D matters, and the magnitude of how much it matters is estimated in terms of a per-capita R&D elasticity of new patent applications. Our estimates are that at the EPA a 10 percent increase in (one-year lagged) R&D is associated with an increase in new patent applications of more than 20 percent.

Reflecting on the Trump Administration's call for return on investment estimates to federal R&D in, for example, federal agencies and their laboratories, perhaps our effort to calculate a per-capita R&D elasticity at the EPA is a first step in that direction. Being the first estimate of a public sector knowledge production function, there are no benchmark elasticities for comparison.15 Still, our estimate of the per-capital R&D elasticity should not be generalized to other U.S. federal agencies because it comes from only EPA technology transfer data. It does, however, provide a meaningful point estimate which might encourage additional research related to other agencies.

In addition to addressing the policy issue of a return on investment to R&D in federal agencies and their laboratories, this paper expands codified knowledge about technology transfer from federal agencies (albeit that we have analyzed only one agency) by addressing the role of invention disclosures as precursors to patent applications. Invention disclosures are an area that commands additional investigation.

Although others who have estimated the R&D-to-patenting relationship among private sector firms have measured patenting in terms of new patent applications, it is important to point out, especially with an eye toward a future research agenda, that an increase in new patent applications is not in itself a measure of the economic impact of transferred technology from a federal agency, but it definitely is an early indication of it. An increase in new patent applications might lead to an increase in patents granted, an increase in patents granted might lead to an increase in licensing activity, and an increase in licensing activity might lead to broad economic impacts associated with transferred technologies from the EPA and from other federal agencies. As more data on technology transfer metrics from federal agencies become available, and efforts toward this goal were directly called for in the Obama Presidential Memorandum in 2011 and were indirectly called for in the recent Trump President's Management Agenda, more comprehensive estimates of the economic impact of federal investment in R&D through licensed technologies could be constructed.

Disclosure statement

No potential conflict of interest was reported by the authors.

Notes

1. As stated in the FTTA, a CRADA is

   "any agreement between one or more Federal laboratories and one or more non-Federal parties under which the Government, through its laboratories, provides personnel, services, facilities, equipment, or other resources with or without reimbursement (but not funds to non-Federal parties) and the non-Federal parties provide funds, personnel, services, facilities, equipment, or other resources toward the conduct of specified research or development efforts which are consistent with the missions of the laboratory … "
2. A public effort to assess the economic contributions of federal R&D is certainly not new. See, for example, the National Academies (2011).
3. See, https://www.nist.gov/tpo/return-investment-roi-initiative/unleashing-american-innovation-symposium.
4. The relevant literature on CRADAs is summarized in Chen, Link, and Oliver (2018).
5. The technical name of this Act is the Clean Air Amendments of 1970.
6. The technical name of this Act is the Federal Water Pollution Control Act Amendments of 1972.
7. Other legislations include the Environmental Quality Improvement Act (1970), the Ocean Dumping Act (1972), the Coastal Zone Management Act (1972), the Marine Protection Research and Sanctuaries Act (1972), the Endangered Species Act (1973), the Marine Mammal Protection Act (1972), the Deepwater Ports and Waterways Safety Act (1974), the Fish and Wildlife Coordination Act (1974), the Wild and Scenic Rivers Act (1976),

the Water Resources Planning Act (1977), the Water Resources Research Act (1977), and the Environmental Education Act of 1990 (Wisman 1985).

8. The source for the Technology Partnership Office reports is each agency's report, all of which are now, under the Technology Transfer Commercialization Act of 2000 (Public Law 106-404), prepared annually.
9. See, https://www.nist.gov/tpo/federal-laboratory-interagency-technology-transfer-summary-reports
10. An invention disclosure is generally an agreement between the federal agency or one of its laboratories and an employed scientist or researcher regarding the ownership of the invention. Generally, a scientist or a researcher completes an invention disclosure through the agency's or laboratory's technology transfer office as a first step for the office to consider patenting the invention. See Bradley, Hayter, and Link (2013) on disclosures at universities.
11. Of course, not all R&D-based knowledge manifests itself in new patent applications; such new knowledge can manifest itself in terms of publications or even, in the case of small entrepreneurial firms, in terms of internal secrets (Hayter and Link 2018).
12. More generally, the production function for patent applications may be unknown, so that estimating equations such as (3) and (4) cannot be derived. In this case, it may be of interest to estimate a semi- or non-parametric regression model for patent applications. This would likely require a larger sample size. In this paper we therefore maintain the conventional parametric framework.
13. While we use a time series of patent application data for a single unit (agency), much of the empirical literature on patenting activity is based on analyses of panel data sets. With a panel, one could use the Poisson fixed or random effects estimator of Hausman, Hall, and Griliches (1984). Cincera (1997) and Blundell, Griffith, and Windmeijer (2002) discuss panel data estimators that relax some of the parametric assumptions underlying the Poisson and negative binomial models. More recently, Charlot, Crescenzi, and Musolesi (2015) have proposed a semi-parametric generalized additive model to analyze regional knowledge production functions in Europe.
14. This test is equivalent to a t-test in a regression of the residuals on lagged residuals and covariates. See, for example, Godfrey (1988) and White (1992).
15. Our elasticity estimate is about four times of that presented by Czarnitzki, Kraft, and Thorwarth (2009, 142), using a model similar to that in equation (2), but without disclosures (D), for a sample of private sector Flemish firms.

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