

Invention disclosures and the slowdown of scientific knowledge

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Abstract:

Invention disclosures are one measure of new scientific knowledge that represents and predicts the future scientific research output of a US federal laboratory. In this article, we document a negative shift in the production function for new scientific knowledge as measured by invention disclosures at one federal laboratory, the National Institute of Standards and Technology, over the first 16 years of the new millennium. We find a negative shift of the production function for new scientific knowledge, and that shift might reflect the coincidence of the information and communication technology revolution that enabled fast science, and the evaluation of research with uncritical use of citation counts that created incentives to focus on incremental research in crowded research topics.

Keywords: invention disclosures | federal laboratory | scientific knowledge | knowledge production function | information and communication technology revolution

Article:

1. Introduction

Invention disclosures mark an initial step in the process of transferring technologies that are created in US federal laboratories.¹ These technologies are eventually transferred to licensees that use them to provide new or improved products and services. Such technology transfer has been the focus of US public policy since the late 1970s.² In this article, we document a negative

¹ According to US Code, Title 15 (Chapter 63, § 3703): 'Federal laboratory means any laboratory, any federally funded research and development center, or any center ... that is owned, leased, or otherwise used by a Federal agency and funded by the Federal Government, whether operated by the Government or by a contractor. ... Federal agency means any executive agency ... as well as any agency of the legislative branch of the Federal Government.'

² There are elements about the transfer of scientific knowledge to the private sector in Bush (1945).

shift in the knowledge production function, with invention disclosures being the measure of new scientific knowledge.

In the early 1970s, and then again in the late 1970s and early 1980s, the US economy experienced a significant slowdown in productivity growth. In response, US President Jimmy Carter initiated in 1979 a Domestic Policy Review. Eight corrective policy initiatives were proposed in his Review, the first of which was ‘to improve the transfer of knowledge from Federal laboratories’ (Carter 1979: 64). Soon thereafter, the US Congress passed the Stevenson-Wydler Technology Innovation Act of 1980 (Public Law 96-480):

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.

While not an amendment to the Stevenson-Wydler Act, technology transfer from federal laboratories was later emphasized in *US Technology Policy*, issued by US President George W. Bush in 1990 (Executive Office of the President 1990: 1–6):

Government policies can help establish a favorable environment for private industry [by improving] the transfer of Federal laboratories’ R&D results to the private sector [and by expediting] the diffusion of the results of Federally-conducted R&D to industry, including licensing of inventions

The importance of technology transfers from federal laboratories on economic growth was again emphasized in US President Obama’s (2011) Presidential Memorandum. President Obama wrote (Obama 2011): ‘One driver of successful innovation is technology transfer, in which the private sector adapts Federal research for use in the marketplace.’ US President Donald Trump in The President’s Management Agenda also emphasized that (Trump n.d.: 47): ‘For America to maintain its position as the leader in global innovation ... it is essential to optimize technology transfer’

The technology transfer process begins with a laboratory’s research and development (R&D) activity that leads to invention disclosures.³ Invention disclosures, which represent new scientific knowledge, lead to patent applications and, when the applications are successful, to patents. Once patents have been filed, negotiations with potential licensees can begin. Licenses to organizations in the public and private sectors generate licensing royalties that flow back to the initiating federal laboratory and inventor (GAO 2018).

There has been a paucity of research on the technology transfer process as it relates to federal laboratories. The absence of relevant research was a motivating factor behind President Obama’s (2011) Presidential Memorandum. The literature to date has focused almost exclusively on the

³ According to the US Code of Federal Regulations, (37 C.F.R. § 501.3(d)), an invention is defined as ‘any art or process, machine, manufacture, design, or composition of matter, or any new and useful improvement thereof, or any variety of plant, which is or may be patentable under the patent laws of the United States’. See <https://ecfr.io/Title-37/se37.1.501_13> (accessed September 5, 2020).

relationship between R&D and patent applications, or even R&D and licensing royalties, in an effort to quantify the returns to R&D (Link 2019; Link and van Hasselt 2019; National Institute of Standards and Technology (NIST) 2019). Surprisingly, again perhaps for lack of suitable data, researchers have ignored the first step in the technology transfer process, namely the relationship between R&D and invention disclosures.

In this article, in the context of a knowledge production function, we identify covariates with invention disclosures at one federal laboratory within the US Department of Commerce: the National Institute of Standards and Technology (NIST).⁴ We document a strong negative shift in the knowledge production function over the first 16 years of the new millennium. Our model, presented in Sections 2 and 3, is a variant of a knowledge production function first introduced to the literature by Griliches (1979), and the data we analyze on invention disclosures are discussed in Section 4.^{5,6} The empirical results from the estimation of our model are in Section 5, and concluding remarks are offered in Section 6.

2. The production of scientific knowledge

A scientific knowledge production function for an economic unit might be represented as $Q = f(K, L)$, where Q represents scientific research output (which will be estimated in the following sections in terms of the count of new invention disclosures by fiscal year), K represents the available stock of scientific research capital, and L represents scientific research labor services. In this article, we isolate shifts in such a scientific knowledge production function after first accounting for the effects of technical capital costs and scientific personnel costs. The result of developing the rate of growth of output as a function of the growth in the inputs (followed in the next section by an empirical description of the relationships) is to quantify the trend in technological advancements in invention disclosures, that is, in new scientific knowledge.

⁴ NIST is the national metrology laboratory in the USA. It is the federal laboratory responsible for the advancement of measurement science, standards, and new technology in order to promote innovation and industrial competitiveness in ways that enhance economic security and improve our quality of life. See <<https://www.nist.gov/about-nist/our-organization/mission-vision-values>> (accessed September 5, 2020). See Link (2019) for a brief history of NIST.

⁵ Federal laboratory employees are required to complete a disclosure form and submit it to their technology transfer office. An invention disclosure form is a vehicle through which the laboratory collects information pertaining to inventions created by federal and non-federal employees who create an invention using laboratory facilities. As stated on NIST's disclosure form: 'The collection of this information is required to protect the United States rights to inventions created using Federal resources. The information collected on the form allows the Government to determine: (1) If an invention has been created; (2) the status of any statutory bar that pertains to the potential invention or that may pertain to the invention in the future. The information collected may allow the Government to begin a patent application process.' See <<https://www.federalregister.gov/documents/2019/08/07/2019-16882/proposed-information-collection-nist-invention-disclosure-and-inventor-information-collection>> (accessed September 5, 2020).

⁶ The NIST invention disclosure form, NIST DN-45, is available through the NIST online service portal. Key questions on the form related to the invention are: 'Describe what the invention is, what is new, how it works, what problem it solves, what its limitations are. Please attach all relevant descriptions from papers or presentations.' And, 'Briefly describe how the invention would be commercially and/or technically superior to current practice.' We thank Courtney Silverthorn, Acting Director of the Technology Partnerships Office at NIST, for making this form available to us.

Our emphasis on technological advancements in new scientific knowledge, albeit for only one federal laboratory, is motivated not only by the opportunity to contribute to a more complete understanding of the technology transfer process by investigating a stage of activity at its genesis, but also to offer complementary empirical evidence, from an important source of new knowledge, to support the affirmative answer to the question posed by Bloom et al. (2020): are ideas getting harder to find?

3. The production function for scientific knowledge

To isolate shifts in the production function for new scientific knowledge, consider the above production function, $Q = A(t) f(K, L)$, where the shift factor $A(t)$ accounts, in the sense of Solow (1957), for neutral disembodied technological change. It follows, using the ‘dot’ notation for time derivatives, that:

$$\frac{\dot{Q}}{Q} = \frac{\dot{A}}{A} + s_K \frac{\dot{K}}{K} + s_L \frac{\dot{L}}{L}, \quad (1)$$

where s_K and s_L are the relevant output elasticities. Following Terleckyj (1974):

$$\frac{\dot{Q}}{Q} - s_L \frac{\dot{L}}{L} = \frac{\dot{A}}{A} + \frac{\partial Q}{\partial K} \frac{K}{Q} \frac{\dot{K}}{K} = \frac{\dot{A}}{A} + \frac{\partial Q}{\partial K} \frac{K}{Q}. \quad (2)$$

If we ignore the depreciation of scientific research capital, then \dot{K} can be replaced by the portion of total scientific research expenditures, R^+ , which represents the flow of new scientific research capital, K^+ . Thus:

$$\frac{\dot{Q}}{Q} - s_L \frac{\dot{L}}{L} = \frac{\dot{A}}{A} + \frac{\partial Q}{\partial K} \frac{K^+}{Q} \quad (3)$$

And, the rate of technological change, \dot{A}/A , in the production of new scientific knowledge can then be estimated as the intercept term from Equation (3).

4. Description of the data

The data used to estimate Equation (3) are in Table 1.⁷ They relate to research activity that occurred at NIST.⁸ Scientific research output, Q , is measured in terms of new invention disclosures.

Table 1. Data for estimation of Equation (3) for NIST invention disclosures

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Fiscal Year	Number NIST invention disclosures Q	\dot{Q}/Q	Intramural R&D budget (\$2015, 000s) R^+	Scientific research capital costs (\$2015, 000s) K^+	K^+/Q	Scientific labor costs (\$2015, 000s) L	\dot{L}/L	Scientific labor's relative share s_L	$dARRA$
2000	32	-0.25	309,428	105,953	3,311.031	203,475	0.0255068	0.6576	0
2001	24	-0.4166667	343,094	134,429	5,601.208	208,665	0.0411521	0.6082	0
2002	14	0.1428571	352,096	134,844	9,631.714	217,252	-0.0135097	0.6170	0
2003	16	0.4375	369,088	154,771	9,673.188	214,317	0.073312	0.5807	0
2004	23	-0.173913	328,160	98,131	4,266.565	230,029	-0.0237101	0.7010	0
2005	19	-0.4736842	354,187	129,612	6,821.684	224,575	-0.0316776	0.6341	0
2006	10	1.9	351,564	134,103	13,410.3	217,461	0.0443206	0.6186	0
2007	29	0.3793103	388,379	161,280	5,561.379	227,099	0.0313167	0.5847	0
2008	40	-0.1	380,177	145,966	3,649.15	234,211	0.0700223	0.6161	0
2009	36	-0.1666667	427,175	176,564	4,904.556	250,611	0.1138338	0.5867	1
2010	30	-0.1666667	529,217	250,078	8,335.934	279,139	-0.0735583	0.5275	1
2011	25	1.08	414,309	155,703	6,228.12	258,606	0.041047	0.6242	1
2012	52	-0.3653846	434,280	165,059	3,174.211	269,221	0.0191813	0.6199	1
2013	33	0.2424242	455,818	181,433	5,497.97	274,385	0.0292837	0.6020	1
2014	41	0.1219512	482,627	200,207	4,883.098	282,420	0.0397458	0.5852	1
2015	46		504,612	210,967	4,586.239	293,645		0.5819	1

Notes: All data pertain to fiscal years. Data on invention disclosures (column (1)) and nominal cost data (columns (3), (4), and (6)) came from NIST; cost data are converted to \$2015 using the GDP deflator.

NIST's total scientific research expenditures, R^+ , are measured in terms of its intramural R&D budget as shown in column (3). That budget is divided between scientific research capital costs, K^+ , in column (4) and scientific labor costs, L , in column (6). The figures in column (8) show that three-fifths of total intramural R&D was allocated to scientific research labor. The binary variable $dARRA$ equals to 1 for the fiscal years beginning in 2009, and it equals to 0 in the earlier years. This variable enters to determine whether the model performs differently after the passage of the American Recovery and Reinvestment Act (ARRA) of 2009 during which time

⁷ The construction of Equation (3) follows directly from Link and Scott (2019), and the data in columns (2)–(8) in Table 1 were previously used in Link and Scott's (2019, 2020) study of scientific publications at NIST. In those previous papers, the dependent variable was scientific publications. The use of invention disclosures in this article is more than a repeat of previous analyses with a new dependent variable. As explicitly noted in GAO (2018), the technology transfer process in federal laboratories begins with the creation of new scientific knowledge, which we measure in this article with invention disclosures. The productivity growth of new scientific knowledge has not previously been investigated within the context of a federal laboratory, or within the context of other research organizations. Thus, our emphasis on invention disclosures might be a salvo to generate economic research into what might be called the economics of epistemology. Or, less ambitiously, our emphasis on invention disclosures might simply urge others to test the prophecy of de Solla Price (1963) about the impending breakdown in what had been exponential growth of science.

⁸ We thank Dr. Gary Anderson, then Senior Economist within the Technology Partnerships Office at NIST, for graciously sharing these data.

NIST received additional intramural R&D. Descriptive statistics on the variables in Table 1 that are used to estimate Equation (3) are presented in Table 2.

Table 2. Descriptive statistics for the variables used in the model of invention disclosures

Variable	<i>n</i>	Mean	SD	Minimum	Maximum
\dot{Q}/Q	15	0.146	0.631	-0.474	1.9
K^+/Q	16	6,221.0	2,778.4	3,174.2	13,410.3
\dot{L}/L	15	0.0258	0.0465	-0.0736	0.114
s_L	16	0.609	0.0382	0.528	0.701
$dARRA$	16	0.438	0.512	0	1

5. Estimates from the model

The ordinary least squares (OLS) regression estimates of Equation (3) are presented in Table 3. The estimated coefficient for the flow of new research capital per unit of output provides an estimate for the annual rate of return, $\partial Q/\partial K$, to research capital. Hence, the estimated annual rate of return to the stock of scientific research capital is 0.00015 or 1.5 invention disclosures for an increase of \$10,000,000 in scientific research capital stock. The intercept term provides the estimate of \dot{A}/A , the annual rate of change in the shift factor—an estimate of the annual rate of technological change in scientific research output. That estimate is negative; it is -0.836, meaning that technological change in the production of invention disclosures decreased at 83.6 per cent per year on average over the first 16 years of the new millennium. The estimated coefficient on $dARRA$ is insignificant whether entered alone for an intercept effect or as an interaction with the explanatory variable for a slope effect, or both.⁹

Table 3. OLS regression estimation of Equation (3), dependent variable: $\dot{Q}/Q - s_L(\dot{L}/L)$, $n = 15$

Variable	Coefficient (standard error) (P > t)
$K^+/QK^+/Q$	0.000153 (0.0000439) (0.004)
Constant	-0.836 (0.303) (0.016)
$F(1, 13)$	12.1
(P > F)	(0.0041)
R^2	0.482
Durbin–Watson d-statistic (2, 15)	2.22
Durbin’s alternative test for autocorrelation	
Chi-squared (1)	0.328
(P > chi-squared)	(0.567)
LM test for ARCH	
Chi-squared (1)	0.028
(P > chi-squared)	(0.867)

6. Concluding remarks

⁹ The Durbin–Watson statistic and Durbin’s alternative test statistic show that first-order autocorrelation is not an issue. The Lagrange multiplier (LM) test for autoregressive conditional heteroskedasticity (ARCH) effects shows that ARCH is not an issue either.

Any generalizations from our analysis should be made with caution. We studied only one federal laboratory, NIST, in this article, and our choice to study that laboratory was motivated by access to a unique set of data. NIST's invention disclosures in the new millennium have been slightly under 500, and the Technology Partnerships Office at NIST estimates that invention disclosures from all of the research agencies over that time period are greater than 65,000. This caveat aside, this article is to the best of our knowledge the first to study invention disclosures over time in any federal laboratory. Thus, it does provide a point of reference for future studies of the activity that is the genesis of federal laboratory technology transfer, and it benchmarks a feasible method for those studies.

Our main finding is that the annual rate of technological advancement in new scientific knowledge, as measured here in terms of invention disclosures, has been declining, at least at NIST, during the new millennium.¹⁰ Why?

Bloom et al. (2020) suggest that one reason for observing such a phenomenon for private-sector firms is that their R&D might have moved toward more defensive research as global competition became more competitive. However, our findings relate to one federal laboratory, so the shift in R&D focus explanation might not apply. What might be an explanation, or we should say a hypothesis worth investigating, is the following.

The start of the information and communication technology (ICT) revolution might be dated to the year 2000, the first year of data in Table 1.¹¹ As the ICT revolution progressed, researchers were able to communicate virtually, which increased the speed of their research, and that in turn increased the speed with which new scientific knowledge could enter society. Perhaps as the speed of conducting a unit of research increased, the impact of that unit of research decreased because the scientists involved would have taken less time to contemplate how best to address their research question under consideration and to develop the implications of their research findings.

Bhattacharya and Packalen (2020) observe that the pervasive use of citation counts as the measure for evaluating the impact of research has provided an incentive for scientists to focus on incremental science rather than exploratory projects that will frequently fail and yet have the potential to develop major advances in scientific knowledge. We have observed a negative shift in the knowledge production function, with new scientific knowledge measured by invention disclosures resulting from the research in the federal laboratory NIST. The negative shift may be a manifestation of the coincidence of the ICT revolution that enabled fast science and the incentive to focus on incremental research in order to add to crowded areas of research where many citations are in the offing for new papers adding incrementally to an already large and growing literature.

¹⁰ This conclusion is not at odds with our earlier findings (Link and Scott 2019) which show that the annual rate of change in the production of scientific publications, an open source vehicle for new scientific knowledge, has been declining since the early 1970s at the then National Bureau of Standards (NBS), and then declining even faster at the reorganized and renamed NIST in 1988.

¹¹ Choosing year 2000 as a starting point for what is called the ICT revolution is consistent with OECD data on the growth of total communication access paths in OECD countries as a group and in the USA. See <<http://www.oecd.org/internet/broadband/oecdkeyictindicators.htm>> (accessed September 5, 2020). See also table 2.6 at <<http://www.oecd.org/sti/deo-tables-2015.htm>> (accessed September 5, 2020).

Invention disclosures arguably capture effective new scientific knowledge more accurately than, for example, the scientific publications describing the research from which both the disclosures and the publications originate. It is therefore particularly concerning that the estimated annual rate of decline in the shift factor for the knowledge production function is 10 per cent during the NIST era when the measure of scientific research output is scientific publications (Link and Scott, 2019) but is 84 per cent when the measure is invention disclosures.

To the extent that the strong negative rate of change in the shift factor for the production function for new scientific knowledge is a bellwether of trends in economic growth—and it may well be so because NIST efficiently provides the technology infrastructure that enables R&D, technological change, and ultimately economic growth—our findings in this article might reasonably suggest the importance of new technology policy (Link and Scott 2011). The form of that new technology policy, from a narrow perspective, will likely be how to incentivize federal laboratories to invest more in new scientific knowledge. From a broader perspective, the form of that new policy will likely depend on how the public sector answers the following questions: is it possible that the technology transfer efforts of federal agencies endeavoring to establish intellectual property in the scientific research output from their laboratories are actually counterproductive? If the publicly funded research in the federal laboratories was published and freely available to all, but no time spent with the formality of invention disclosures and the pursuit of intellectual property and licensing arrangements, would the inventions from the federal laboratories increase?¹²

Conflict of interest statement. None declared.

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