Technology transfer at the U.S. National Institute of Standards and Technology

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Abstract:

This article analyzes the interrelationship among technology transfer mechanisms using data specific to the US National Institute of Standards and Technology (NIST). An overview of the history of NIST and US policies that emphasize the economic importance of technology transfer are discussed. The empirical analysis focuses on NIST investments in research and development (R&D) and the cascading impact of those investments on new inventions disclosed, new patent applications, new patents issued and new patent licenses; and accounting for the effects of R&D on these three investments, an overall estimate of the R&D elasticity of new patent licenses is calculated to be 0.7976. The article concludes with a policy-focused summary of the implications of the empirical findings, and a suggested road map for future research related to technology transfer from US federal laboratories.

Keywords: technology transfer | federal laboratories | NIST | R&D | patents

Article:

> Technology transfer is the overall process by which NIST knowledge, facilities or capabilities in measurement science, standards and technology promote U.S. innovation and industrial competitiveness in order to enhance economic security and improve quality of life.
>
> —NIST definition of technology transfer

1. Introduction

While the origin of the concept of technology transfer is uncertain, many might agree that an early emphasis in the USA on the transfer of technical knowledge and technology traces at least to Vannevar Bush's *Science—the Endless Frontier*.[1] On 17 November 1944, President Franklin

[1] A more detailed discussion of the origin of the concept of technology transfer and the early legislative history of technology transfer at NIST is in Link and Oliver (2019).

D. Roosevelt sent a letter to Bush in which he articulated a role for, and the national importance of, transferring publicly-developed technical knowledge and technology to the public and private sectors of the economy[2]:

> Dear Dr. Bush:
> There is, however, no reason why the lessons to be found in this [war] experiment cannot be profitably employed in times of peace. The information, the techniques, and the research experience developed by the Office of Scientific Research and Development and by the thousands of scientists in the universities and in private industry, should be used in the days of peace ahead for the improvement of the national health, the creation of new enterprises bringing new jobs, and the betterment of the national standard of living.

Bush's 5 June 1945 response to President Harry S. Truman rephrased a portion of President Roosevelt's charge in the form of a question, which Bush himself went on to answer in *Endless Frontier* (Bush, 1945: 1). That question was: 'What can the Government do now and in the future to aid research activities by public and private organizations?' Bush's response to this question emphasized his view of the importance of the transfer of scientific and technical knowledge from the public sector to others to use in the development of new and more productive physical technologies for the betterment of our nation. However, Bush did not address any specific mechanisms for technology transfer, but perhaps his emphasis on the transfer of scientific knowledge *per se* planted seeds for future public policies that would explicitly emphasize the transfer of federally funded and developed technology for the common weal.

As important as the topic of technology transfer and the policy implications of technology transfer may be, an initial question with regard to this article is: why study technology transfer from the National Institute of Standards and Technology (NIST), a Government-Owned Government-Operated (GOGO) federal laboratory within the Department of Commerce (DOC)? First, from an historical perspective, one could make the case that the activities set out in the 1901 enabling legislation that established the National Bureau of Standards (NBS), the predecessor organization to NIST, represents the first legislated national description of effort to transfer technology from the public sector, in the form of technical knowledge, throughout the economy. Second, from a policy perspective, the Technology Partnerships Office at NIST coordinates the annual reporting to the Office of the President and the Congress about technology transfer activities at all major agencies.[3] And finally third, from a pragmatic perspective, NIST provides more public domain data on its technology transfer mechanisms than any other federal laboratory as evidenced from the Technology Partnerships Offices' annual reports.

Given the NIST definition of technology transfer in the epigram at the beginning of this article, the discussion and analysis of technology transfer at NIST in Section 2 begins with an historical overview of the US history of establishing standard weights and measures at NBS. In other words, the premise is that the establishment of standard weights and measures, and the

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[2] For a more detailed discussion of Bush's influence on public policy, see Leyden and Link (2015) and Leyden and Menter (2018).
[3] See <https://www.nist.gov/tpo> accessed 11 Mar 2019.

distribution of those standards to the states within the USA, is part of the genesis of public sector technology transfer activity in the USA. And, given that the US history of technology transfer began with the establishment of standard weights and measures at the organization that would later become NIST, it seems fitting to study technology transfer activities from that organization.

Section 3 provides an overview of recent US public policies in support of technology transfer activity at federal laboratories. Surprisingly, the academic and policy literatures are relatively void of agencywide studies of technology transfer. While NIST has sponsored a significant number of economic impact studies of its investments in infrastructure technology in which technology transfer mechanisms have been highlighted as vehicles for related private and social benefits (Link and Scott 2012), aggregate analyses that follow an analytical model, as presented in the following section, are missing.

Section 4 presents a model of how the following technology transfer mechanisms might be interrelated: new inventions disclosed, new patent applications, new patents issued and new patent licenses. These technology transfer mechanisms are generally viewed as the traditional ones, and Link and Oliver (2019) make the case that their traditionalisms might come from the fact that they are the mechanisms with generally available measures in the public domain. The interrelationships among these traditional technology transfer mechanisms have yet to be studied at any US federal laboratory in a systematic and integrated manner.[4] In an effort to begin to fill this void—and filling this void is important given the Obama and Trump Administrations' recent emphasis on understanding and quantifying the economic role and importance of technology transfer from federal laboratories—empirical estimates of these interrelationships using public domain data relevant to NIST are presented. A premise of this article is that a requisite step toward estimating a return on investment (ROI) from research and development (R&D) in federal laboratories (discussed in Section 3) is to understand the technology transfer mechanisms affected by R&D because technical knowledge and developed technology enters the economy through, for example, new patent licenses. New patent licenses are a technology transfer mechanism that represents new technology being adopted and eventually put into use in the economy, and new technology must enter the economy for federal laboratory-based social benefits to begin to be realized.[5]

Finally, in Section 5, we discuss the policy implications of our empirical findings, and we suggest a road map for future research related to technology transfer from federal laboratories, in general, and NIST, in particular.

2. An historical basis for US technology transfer

2.1. Standard weights and measures

At the beginning of the twentieth century, the USA was the only major economy without a standards laboratory. It was Lyman Gage, then US Secretary of the Treasury, who championed a national standards laboratory. His efforts were instrumental in the passage of the 3 March 1901

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[4] An initial step toward this effort was by Link and van Hasselt (2019) who related R&D investments and new inventions disclosed to new patent applications using US agency technology transfer data.

[5] For a model of the economics of technology transfer, see Link and Scott (2019).

Act (Public Law 177-56), often referred to as the Organic Act of 1901. With regard to the Office of Standard Weights and Measures, to be renamed the National Bureau of Standards (NBS), within the Department of the Treasury, the Organic Act states:

> That the functions of the [B]ureau shall consist in the custody of the standards; the comparison of the standards used in scientific investigations, engineering, manufacturing, commerce, and educational institutions with the standards adopted or recognized by the Government; the construction, when necessary, of standards, their multiples and subdivisions; the testing and calibration of standard measuring apparatus; the solution of problems which arise in connection with standards; the determination of physical constants and the properties of materials, when such data are of great importance to scientific or manufacturing interests and are not to be obtained of sufficient accuracy elsewhere.

The Organic Act of 1901 and the activities of the Bureau might reasonably be viewed as the first national effort to legislate the transfer of technology in the form of technical knowledge from the public sector throughout the economy.

2.2. The National Bureau of Standards

In late 1901, the Bureau was transferred from the Department of the Treasury to the newly-established Department of Commerce and Labor. Initially, more than one-half of the testing at the Bureau was for government use rather than for the use of enhancing commerce. For example, as early as 1906, 'there was a wave of reform going on all through the Government service as to proper specifications and proper tests to determine whether goods purchased [by the Government] complied with specification' (Cochrane 1966: 91). The goods tested ranged from light bulbs to the tensile strength of elevator cables. As more and more goods were rejected, manufacturers began to interact with the Bureau 'for advice and help with their materials, measuring, and testing apparatus, and methods of quality control' (Cochrane 1966: 92).

World War I brought about an even greater understanding for the need for standardization across agencies that purchased goods that are supply chain related. Thus, the transfer of technology—tacit technical knowledge in the form of know-how as well as codified practices—from the public sector's Bureau to private sector manufacturers had begun, and it increased exponentially during the first decade of the Bureau's life (Cochrane 1966).

After World War I, then Secretary of Commerce Herbert Hoover initiated an industrial survey for the purpose of identifying wasteful practices in industry. The industrial survey concludes that as much as 25 percent of production costs could be eliminated without affecting quality (Cochrane 1966). This finding motivated a wider role for standardization, and this thinking was later exacerbated by the spread of assembly line production to more efficient use of economic inputs. Yet again, the Bureau's technical knowledge was being transferred to industry and eventually to consumers.

However, during World War II, the role of the Bureau expanded to focus on the development and improvement of military technology. And, by the end of World War II, there was the view that the federal government, through the expertise of the Bureau, should be responsible for basic research—the discovery of new knowledge—rather than applied industrial research.

In 1953, Secretary of Commerce Sinclair Weeks asked the National Academy of Sciences to ‘convene an *ad hoc* committee to evaluate the function and operations of the NBS in relation to the current national needs’ (Cochrane 1966: 495). Perhaps most relevant, from a technology transfer to the private sector perspective, was the recommendation from the Academy’s *ad hoc* committee that the weapons programs at the NBS be transferred to the Department of Defense. The *ad hoc* committee recommended that the Bureau be restored to its ‘essential services for our industrial society’ (Cochrane 1966: 496). The *ad hoc* committee also made a recommendation for the modernization of the Bureau’s facilities which were ‘in a sordid mess’ (Cochrane 1966: 503). After much debate and planning, ground was broken on 14 June 1961 on a 550-acre plot of land in Gaithersburg, Maryland. The Gaithersburg campus was dedicated in 1966.

2.3. Renaming the National Bureau of Standards to the NIST

As Schooley (2000: 646) suggested:

> Given the increased emphasis on international competitiveness, technology transfer, and industrial productivity in the dialog between NBS and Congress during the 1980s, new legislation to re-define the mission of the Bureau was almost a certainty. The change in the name of the agency—in the view of the Congress—merely served to underscore its new role within the Department of Commerce.

It was a well-known fact by the mid- to late-1970s that many US industries were faltering in terms of their technological advances. For example, total factor productivity is widely regarded as an index of technological advancement within an economy. Much has been written about the culprits for the productivity slowdown (Link and Siegel 2003; Leyden and Link 2015), but most scholars point to declining investments in R&D as a cause of a slowdown in technological advancements, which, in turn, was holding down productivity growth. Causes aside, one consequence of these slowdown periods was a decline in the international competitiveness of many US industries.[6]

In fact, the Technology Administration within the DOC reported, based on data and information relative to the mid- to late-1980s, trends in several emerging technologies in which the USA was losing, and in some instances losing badly, to Japan in particular (DOC 1990: 13):

- The USA was losing in terms of trends in R&D investments in advanced materials, biotechnology, digital imaging technology, sensor technology and superconductors.

[6] There were a number of Congressional responses to this productivity slowdown, including making changes in the range of R&D mechanisms to support a more efficient progression through the phases of R&D. For example, as stated in the Joint Research and Development Act of 1984: ‘Joint research and development as our foreign competitors have learned [Japan] can be pro-competitive. It can reduce duplication, promote the efficient use of scarce technical personnel, and help to achieve desirable economies of scale [in R&D].’

- The USA was losing in terms of trends in new product introductions in advanced materials, advanced semiconductor devices, high-density data storage, high-performance computing, medical devices and diagnostics (including digital imaging technology), optoelectronics and superconductors.

In the mid-1980s, Congress considered 'several initiatives to improve American competitiveness in world-wide markets' (Schooley 2000: 613). These considerations were finally codified in the Omnibus Trade and Completeness Act of 1988 (Public Law 100-418). Stated therein[7]:

> The National Bureau of Standards since its establishment has served as the Federal focal point in developing basic measurement standards and related technologies, has taken a lead role in stimulating cooperative work among private industrial organizations in efforts to surmount technological hurdles, and otherwise has been responsible for assisting in the improvement of industrial technology … It is the purpose of this Act to rename the National Bureau of Standards as the National Institute of Standards and Technology [NIST] and to modernize and restructure that agency to augment its unique ability *to enhance the competitiveness of American industry* (emphasis added) … The Secretary of Commerce ... acting through the Director of the Institute … and, if appropriate, through other officials, is authorized to take all actions necessary and appropriate to accomplish the purposes of this Act, including the following functions of the Institute … to invent, develop, and (when appropriate) promote *transfer to the private sector* (emphasis added) of measurement devices to serve special national needs … to demonstrate the results of the Institute's activities by exhibits or other *methods of technology transfer* (emphasis added), including the use of scientific or technical personnel of the Institute for part-time or intermittent teaching and training activities at educational institutions of higher learning as part of and incidental to their official duties …

3. Recent technology transfer legislation

3.1. Legislation about technology transfer from US Federal laboratories

Jumping ahead several decades, President Jimmy Carter, as part of his 1979 Domestic Policy Review, specifically emphasized the importance of the transfer of federally-funded technical knowledge[8]:

> 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*

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[7] The section (Subtitle B, Part I) of the Omnibus Trade and Competitiveness Act from which this excerpt about the National Bureau of Standards and the NIST is quoted is called the Technology Competitiveness Act.

[8] See President Carter's Industrial Innovation Initiatives Message to the Congress on Administration Actions and Proposals (31 October 1979): <http://www.presidency.ucsb.edu/ws/index.php?pid=31628> accessed 11 Mar 2019.

> *laboratories* (emphasis added); and, through the State and Commerce Departments, increasing the availability of technical information developed in foreign countries.

In response to President Carter's review, and in response to Congress' awareness and concern about a national productivity slowdown that began in the early 1970s and then accelerated in the late 1970s and early 1980s, Congress passed, among other legislation, the Stevenson-Wydler Technology Innovation Act of 1980 (Public Law 96-480). The 1980 Act focused specifically on technologies developed in federal laboratories:

> Technology and industrial innovation are central to the economic, environmental, and social well-being of citizens of the United States. … 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.

This 1980 Act made clear that it is the responsibility of each federal laboratory to establish an office as well as mechanisms to transfer its technology to those organizations that will benefit:

To enhance the technology transfer mission of federal laboratories, Congress amended the Stevenson-Wydler Act of 1980 in 1986 with the passage of the Federal Technology Transfer Act of 1986 (Public Law 99-502). This 1986 Act allowed federal agencies to enter into CRADAs (cooperative R&D agreements) not only with other firms but also with other federal agencies.

In 1990, President George H. W. Bush issued what might be regarded as the first formal statement of US technology policy. In *US Technology Policy* (Executive Office of the President 1990: 2–6):

> A nation's technology policy is based on broad principles that govern the allocation of technological resources … The goal of U.S. technology policy is to make the best use of technology in achieving the national goals of improved quality of life for Americans, contained economic growth, and national security … While the government plays a critical role in establishing an economic environment to encourage innovation, the private sector has the principal role in identifying and utilizing technologies for commercial products and processes … Government policies can help establish a favorable environment for private industry [by taking steps to] … *[i]mprove the transfer of Federal laboratories' R&D results to the private sector* (emphasis added). Encourage direct laboratory-industry interaction within broad, flexible Federal guidelines, since effective technology transfer occurs at the operational level.

3.2. Renewed interest in technology transfer from US Federal laboratories

Federal laboratories have traditionally transferred their technology through several mechanisms, although those best known are patenting, licensing and CRADA activity. Specific emphasis on these three mechanisms of technology transfer, as well as other mechanisms, gained attention in response to the October 2011 Presidential Memorandum—Accelerating Technology Transfer and Commercialization of Federal Research in Support of High-Growth Businesses.[9] President Obama's memorandum about technology transfer was based on the assumption about a positive relationship between technology transfer and innovation, and a positive relationship between 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.

Although not a formal technology transfer policy, the Trump Administration has raised important issues about technology transfer from federal laboratories. In The President's Management Agenda (undated), the Administration noted (p. 49):

> 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.

Under the heading of a Cross Agency Priority Goal to Improve Transfer of Federally Funded Technologies from Lab to Market in the President's Management Agenda (p. 49), the Administration seeks to 'Improve the transfer of technology from federally funded research and development to the private sector to promote U.S. economic growth and national security.' More specifically, this goal will (p. 49):

- improve the transition of federally-funded innovations from the laboratory to the marketplace by reducing the administrative and regulatory burdens for technology transfer and increasing private sector investment in later-stage R&D;
- develop and implement more effective partnering models and technology transfer mechanisms for Federal agencies; and
- enhance the effectiveness of technology transfer by improving the methods for evaluating the ROI and economic and national security impacts of federally-funded R&D, and using that information to focus efforts on approaches proven to work.

4. Empirical analysis of technology transfer activity

Consider the interrelationship among the technology transfer mechanisms represented by expression (1):

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[9] See <https://obamawhitehouse.archives.gov/the-press-office/2011/10/28/presidential-memorandum-accelerating-technology-transfer-and-commerciali> accessed 11 Mar 2019.

R&D → New Inventions Disclosed → New Patent Applications
→ New Patents Issued → New Patent Licenses

(1)

And, the data used to estimate models implicit in expression (1) are in Table 1.

Table 1. Primary data on NIST technology transfer mechanisms and R&D investments, fiscal years 2000–17.

Fiscal year	New inventions disclosed	New patent applications	New patents issued	New patent licenses	R&D investments (M, $2018)
2000	32	18	14	3	663.6
2001	24	9	20	4	568.3
2002	14	19	18	2	681.1
2003	16	5	7	3	653.7
2004	23	8	10	2	592.1
2005	19	5	9	5	558.7
2006	10	4	6	3	531.3
2007	29	6	3	5	576.9
2008	40	18	2	2	601.5
2009	36	19	7	11	634.6
2010	30	19	10	7	668.8
2011	25	17	14	5	593.6
2012	52	24	12	6	610.0
2013	33	23	20	7	641.9
2014	41	21	19	7	692.7
2015	46	26	19	11	699.1
2016	46	21	15	12	786.9
2017	40	43	31	19	761.5

Note: Based on discussions with NIST personnel, the period between 2007 and 2008 reflects a change in management's view on patent applications that occurred in the mid-2000s.
Sources: <https://www.nist.gov/tpo/department-commerce> accessed 27 Feb 2019; <https://www.aaas.org/programs/r-d-budget-and-policy/historical-trends-federal-rd> accessed 27 Feb 2019.

From the conceptual model in expression (1), the following equations can be estimated to arrive at a quantitative estimate of the relationship between R&D investments at NIST and its technology transfer mechanisms that eventually lead to new patent licenses. From a policy perspective, as mentioned in Section 1 of this article, this is a critical technology transfer related relationship because R&D investments come from policy budget allocation decisions and new patent licenses represent a vehicle through which laboratory developed technology enters the economy.

The analytical model in Equations (2)–(5), often referred to as a mediation model, begins with R&D investments and those investments have a cascading yet indirect effect on new patent licenses. Equation (3) takes into account that R&D investments might also have a direct relationship with New Patent Applications to the extent that additional laboratory research is needed for proof of concept from the disclosure of the invention to NIST ability to submit a patent application to the US Patent and Trademark Office (USPTO). Thus:

$$\ln(\text{New Inventions Disclosed}) = \alpha_1 + \beta_1 \ln(\text{R\&D}) + \varepsilon_1 \qquad (2)$$

$$\ln(\text{New Patent Applications}) = \alpha_2 + \beta_2 \ln(\text{New Inventions Disclosed}) + \beta_3 \ln(\text{R\&D}) + \varepsilon_2 \qquad (3)$$

$$\ln(\text{New Patents Issued}) = \alpha_3 + \beta_4 \ln(\text{New Patent Applications}) + \varepsilon_3 \qquad (4)$$

$$\ln(\text{New Patent Licenses}) = \alpha_4 + \beta_5 \ln(\text{New Patents Issued}) + \varepsilon_4 \qquad (5)$$

where β_1 is the R&D elasticity of new inventions disclosed, β_2 is the new inventions disclosed elasticity of new patent applications, β_3 is the R&D elasticity of new patent applications, β_4 is the new patent applications elasticity of new patents issued (i.e. it reflects the success rate of new patent applications) and β_5 is the new patents issued elasticity of new patent licenses.

It follows from these four equations that the relationship between R&D to new inventions disclosed can be quantified in terms of β_1, the relationship between new inventions disclosed and new patent applications can be quantified in terms of β_2. R&D as well affects new patent applications indirectly through new inventions disclosed (i.e. as $\beta_1\beta_2$) as well as directly through β_3. Thus, the total effect of R&D on new patent applications can be quantified in terms of $(\beta_1\beta_2 + \beta_3)$. It also follows that the R&D to new patents issued relationship can be quantified as $[\beta_4 (\beta_1\beta_2 + \beta_3)]$, and finally the R&D to new patent licenses relationship can be quantified as $[\beta_5\beta_4 (\beta_1\beta_2 + \beta_3)]$.

The econometric results from estimating Equations (2)–(5) are presented in Table 2. Using the estimated coefficients from Table 2, our point estimate of the R&D elasticity of new patent licenses is 0.7976.[10] In other words, our analysis of the NIST data suggests that a 10-percent increase in R&D is related to a 7.98-percent increase in new patent licenses.[11]

Table 2. Estimated regression coefficients from Equations (2) to (6).

	Estimated coefficient			
	(1)	**(2)**	**(3)**	**(4)**
Independent variables	**ln(New Inventions Disclosed)**	**ln(New Patent Applications)**	**ln(New Patents Issued)**	**ln(New Licenses)**
ln(R&D)	2.0628* (0.9951) [0.0586]	2.8320** (1.0115) [0.0142]	–	–
ln(New Inventions Disclosed)	–	0.8271*** (0.2377)	–	–

[10] These four equations were estimated individually. From Table 2, β_1 = 2.0628 from column (1), β_2 = 0.8271 from column (2), β_3 = 2.8320 also from column (2), β_4 = 0.3770 from column (3) and β_5 = 0.4662 from column (4).

[11] On new patent licenses from Equations (2)–(5), 0.7976 is the estimate of the total effect of R&D. One could alternatively arrive at a direct effect of R&D on new patent licenses by estimating the following equation: ln(New Patent Licenses) = $\alpha + \gamma$ ln(R&D) + ε. However, to reconcile the total effect of R&D on new patent licenses, γ, from this equation with the calculated total effect from the mediation model, one would need to assume that R&D has a direct effect on new patents issued (Equation (4)) and on new patent licenses (Equation (5)). Those are assumptions that seem to be unrealistic.

Independent variables	Estimated coefficient (1) ln(New Inventions Disclosed)	(2) ln(New Patent Applications)	(3) ln(New Patents Issued)	(4) ln(New Licenses)
		[0.0037]		
ln(New Patent Applications)	–	–	0.3770* (0.2137) [0.0995]	–
ln(New Patents Issued)	–	–	–	0.4662* (0.2504) [0.0800]
Intercept	−9.9899 (6.4424) [0.1450]	−18.4106 (6.1240) [0.0094]	1.4040 (0.6177) [0.0393]	0.5292 (0.6460) [0.4256]
R^2	0.4818	0.7166	0.5572	0.3627
Durbin Watson	2.0421	2.0091	1.7018	2.1312

Notes: Durbin Watson statistics are Yule–Walker estimates for the maximum autocorrelation correction possible. Standard errors are reported in parentheses ($n = 18$) and p-values are reported in square brackets. ***Significant at the 0.01 level, **significant at the 0.05 level and *significant at the 0.10 level.

5. Policy implications and road map for future research

Regarding policy implications, the empirical results in Table 2 demonstrate the importance of understanding the path through which R&D affects new patent licenses—a proxy for one aspect of the way in which technology transfer to the economy occurs.[12] The Trump Administration's call for measures of the ROI from R&D investments in federal laboratories might be interpreted as a call for ROI measures that link federal laboratory R&D investments to the social benefits that occur in both the public and the private sectors after the transfer of technology. Thus, to develop such ROI measures, an understanding of the path through which R&D affected technical knowledge and technology is transferred is a necessary starting point. And, an understanding of the path through which R&D affects relevant technology transfer mechanisms prior to the technology entering the economy underscores the policy importance of Congress maintaining continuous support of laboratory R&D.

Regarding future research into the transfer of technology from federal laboratories, more emphasis is needed on the nuances of the conceptual model in expression (1) and on the attendant empirical representations of that expression through Equations (2)–(5). The presentation above is only a starting point; lag structures have not been taken into account and technology can enter the economy through other mechanisms besides new patent licenses. For example, technical knowledge is also transferred from a federal laboratory through CRADAs, and internal R&D activity enriches both the tacit knowledge base and the codified knowledge base of a laboratory. In fact, licenses are used to transfer technical knowledge from a federal agency to private participants in CRADAs. An enriched knowledge base is a necessary condition

[12] We thank an anonymous referee for emphasizing that patenting and subsequent licensing are only a small, and sometimes serendipitous, element of the overall intellectual property (IP) developed by NIST. That is, patent licensing is only a small part of NIST IP production and transfer, as its primary mission is to deliver nonproprietary infrastructure technologies to the standards-making arena. However, the academic and policy literatures have continued to focus on patenting and licensing as traditional technology transfer metrics.

for firms and other organizations to find it in their best interest to, for example, engage in CRADA activity.

Future research regarding NIST, or any single laboratory, should also address technology transfer mechanisms specific to that laboratory. For example, much of NIST technology that is transferred is embodied in standards and test methods (Tassey 2017). Those mechanisms, due to a lack of a more complete public domain data set, were not considered in the model above.[13] Perhaps, through case studies, researchers will be able to develop models that trace a laboratory's investments in R&D through its specific, and often many, technology transfer mechanisms and the affected public sector and private sector organizations.

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[13] As documented in Link and Scott (2012), NIST has sponsored over forty economic impact studies related to NIST-specific investments in infrastructure technology, and those case studies emphasized the technology transfer mechanism(s) relevant to the study as well as the private and social benefits attributable to NIST investments.

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