Public science and public innovation: Assessing the relationship between patenting at U.S. National Laboratories and the Bayh-Dole Act.

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Abstract:

Most studies of the effects of the Bayh-Dole Act have focused on universities. In contrast, we analyze patenting activity at two prominent national laboratories, Sandia National Laboratories and the National Institute of Standards and Technology before and after the enactment of this legislation and the Stevenson-Wydler Act. It appears as though the enactment of Bayh-Dole and the Stevenson-Wydler Act were not sufficient to induce an increase in patenting at these labs. However, the establishment of financial incentive systems, embodied in passage of the Federal Technology Transfer Act, as well as the allocation of internal resources to support technology transfer, stimulated an increase in such activity.

Keywords: U.S. National Laboratories | patenting | Bayh-Dole Act | Stevenson-Wydler Act | Federal Technology Transfer Act | patenting activity | national laboratories | financial incentive systems | research policy

Article:

1. Introduction

In recent years, many scholars have considered the impact of the Bayh-Dole Act of 1980 on patenting and licensing by U.S. universities. In general, these academics have concluded that the legislation had a positive and direct impact on these dimensions of technology commercialization.1,2 According to the Act:

> It is the policy and objective of the Congress to use the patent system to promote the utilization of inventions arising from federally supported research or development.

More explicitly, universities, or other institutions of higher learning as well as nonprofit organizations, may elect to retain title to any subject invention conceived or first reduced to practice under a contract, grant, or cooperative agreement entered into with any federal agency. Over time, universities have developed and modified licensing revenue sharing arrangements with faculty inventors to maintain an effective incentive system for faculty to patent through the university's technology transfer office.3

In the academic literature, university technology transfer/commercialization has garnered most of the attention associated with the Bayh-Dole Act. However, a clause in the Act implies that the impact of the legislation should also encompass national laboratories that are government-owned and contractor-operated (GOCO). Specifically, the legislation states that the contractor of a "Government owned research or production facility [may] elect to retain title to any subject invention…." The Department of Energy (DOE) fought such an interpretation of the Bayh-Dole Act for a number of years arguing, correctly according to Walterscheid (1990), that this interpretation changed the long-standing patent policy of DOE that was originally established under the Atomic Energy Act of 1954 as amended and Section 9 of the Federal Nonnuclear Energy Research and Development Act of 1974.

Whereas the Bayh-Dole Act provided a mechanism and incentive system for universities and nonprofit organizations to transfer their technology to industry, the Stevenson-Wydler Technology Innovation Act of 1980 provided a similar and more specific infrastructure for technology to flow from national laboratories to industry.4 According to the Act:

> 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 [non-classified] technology to state and local governments and to the private sector.

Prior to the Stevenson-Wydler Act, technology transfer was not an explicit mission of national laboratories.5 In contrast, the Act mandated that each national laboratory establish an Office of Research and Technology Applications to, among other things, "disseminate information on federally owned or originated products, processes, and services having potential application to state and local governments and to private industry."6,7 The Federal Technology Transfer Act of 1986, which amended the Stevenson-Wydler Act, provided financial incentives to laboratory scientists of "at least 15 percent of the royalties or other income the agency receives on account of any invention to the inventor … if the inventor … was an employee of the agency at the time the invention was made.”

Commercialization at national laboratories has been analyzed along several dimensions. For example, the National Academy of Sciences recently conducted two studies of the potential use of national laboratories to anchor science and technology parks (Wessner, 1999 and Wessner, 2001).8 However, for the purposes of motivating this paper, there have been two quantitative studies of post-1980 patenting at national laboratories. Jaffe et al. (1998) examined patenting activity at NASA and found that it increased in the 1980s, without any decline in the quality of the patents, measured in terms of citations. Jaffe and Lerner (2001) studied patenting in selected Department of Energy (DOE) laboratories and also found that it had increased since the early 1980s and by the early1990s was on par, per dollar of R&D, with universities.9

In this paper, we compare and contrast patenting activity at two prominent national laboratories, Sandia National Laboratories (SNL) in Albuquerque, New Mexico, and the National Institute of Standards and Technology (NIST) in Gaithersburg, Maryland. SNL and NIST present an interesting contrast in terms of size and administrative control. SNL has an annual budget of $2.4 billion and 8500 employees compared to NIST's annual budget of $900 million and 2800 employees,10 and administratively SNL is a government-owned contractor-operated (GOCO) laboratory whereas NIST is a government-owned government-operated (GOGO) laboratory.

Before we begin our analysis of these two laboratories, it is important to note three key differences between research universities and national laboratories. These differences are likely to affect the rate of technology transfer/commercialization. First, universities tend to be more market-driven than national laboratories, which are shielded from market competition. Second, university technology transfer offices, unlike those in the national laboratories, have traditionally encountered strong pressure from university administrators (e.g., presidents and provosts) and those governing these institutions (e.g., state legislators and boards of trustees) to commercialize intellectual property to generate revenue for the university (Siegel et al., 2007).11 Finally, universities tend to be more sensitive to economic fluctuations and business cycles than national laboratories although national laboratories are more sensitive to political shifts. The 18-month economic downturn that began in December 2007 and the resulting decline in state support for universities have exacerbated technology transfer/commercialization pressures.

This study constitutes the first systematic time-series analysis of a national laboratory's patent-related output from investments in public science. More specifically, we assess how technology transfer legislation, which began in 1980 with the Stevenson-Wydler Act, and other institutional events, affected the pattern of patent activity over time at these two laboratories.

In Section 2, we briefly overview the history of SNL and NIST and discuss their current missions. Section 3 describes the data and exploratory econometric estimations of the impact of selected legislation and other institutional events on patenting activity at the two national laboratories. In Section 4 of the paper, we present conclusions, caveats, and suggestions for additional research.

2. Overview of the national laboratories

2.1. Sandia National Laboratories

The roots of SNL trace to the Z-Division at Los Alamos National Laboratory, which was formed in July 1945 for ordinance engineering and assembly as part of the Nation's post-war planning.12 In the fall of 1945, units of the Z-Division were moved to Sandia Base near Albuquerque, New Mexico, due to overcrowding at Los Alamos.13 Building 828 was constructed in 1946 to house mechanical test activities related to the design of new weapons. Under the leadership of Paul Larsen, then director of Z-Division, Sandia Base became Sandia Laboratory in April 1948. After the Soviet Union exploded an atomic weapon, President Eisenhower, “promoted the use of nuclear weapons like any other strategic weapon in the military arsenal” (Sullivan, 2010, p. 2). As a result, the Sandia Laboratory's role in bomb and warhead applications greatly increased. After establishing a second research facility in Livermore, California, Sandia Laboratory became Sandia Laboratories, in 1956. In 1979, it was designated as a DOE national laboratory.14

SNL's funding comes primarily from DOE with supplementary funding from the Department of Homeland Security and the Department of Defense. Research is conducted in five major areas: nuclear weapons, energy and infrastructure assurance, nonproliferation, defense systems and assessments, and homeland security and defense.15 As a GOCO laboratory, Sandia Corporation, a Lockheed Martin company, manages SNL for DOE's National Nuclear Security Administration.16

2.2. National Institute of Standards and Technology

The creation of the National Institute of Standards and Technology stems from a long history of U.S. leaders calling for uniformity in science. The clarion call for uniformity is traceable to several formal proposals for a Department of Science in the early 1880s, along with the explosion of documentary standards in all aspects of federal and state activity. Due to these trends, the establishment of a standards laboratory was inevitable.17 The political force for the establishment of this laboratory was Lyman Gage, Secretary of the Treasury under President William McKinley. Gage's original plan, announced in 1900, was for a separate agency to be called the National Standardizing Bureau. This Bureau would maintain custody of standards; compare, construct, and test standards; and resolve problems in connection with standards. Finally, the Act of March 3, 1901, also known as the Organic Act, established the National Bureau of Standards (NBS) within the Department of the Treasury.

In the period after World War I, the Bureau's research focused on assisting in the growth of industry. Research was conducted on ways to increase the operating efficiency of automobile and aircraft engines, electrical batteries, and gas appliances. Also, work was begun on improving methods for measuring electrical losses in response to public utility needs. This latter research was not independent of international efforts to establish electrical standards similar to those established over 50 years before for weights and measures. After World War II, significant attention and resources were allocated to the Bureau. NBS moved from Washington, D.C. to Gaithersburg, Maryland in 1958, and it was renamed as NIST under the guidelines of the Omnibus Trade and Competitiveness Act of 1988,18 and through the Act the scope of NIST's research mission was expanded.

NIST's mission is to promote U.S. economic growth by working with industry to develop and apply technology, measurements, and standards. NIST carries out this mission primarily through its eight measurement and standards research laboratories. The laboratories at NIST provide technical leadership for vital components of the nation's technology infrastructure needed by U.S. industry to continually improve its products and services.

3. Patenting at the national laboratories

In Fig. 1 and Fig. 2, we present patent applications and patent applications per $R&D (billions, $2009) from 1970 through 2009 at SNL and NIST, respectively.19 In both laboratories, patent applications and patent applications per $R&D increased during the post-1980 period, following a pattern observed at U.S. research universities in the aftermath of the enactment of the Bayh-Dole Act in 1980. However, at SNL and NIST, the rise in patenting did not occur immediately after the Stevenson-Wydler Act; rather, it began in the mid-1980s.

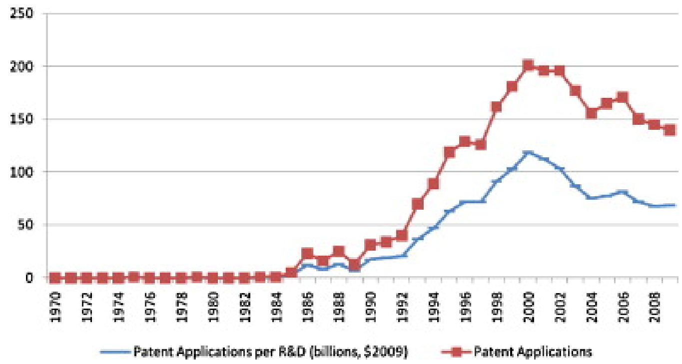

Fig. 1. Patent application trends at SNL: 1970–2009.

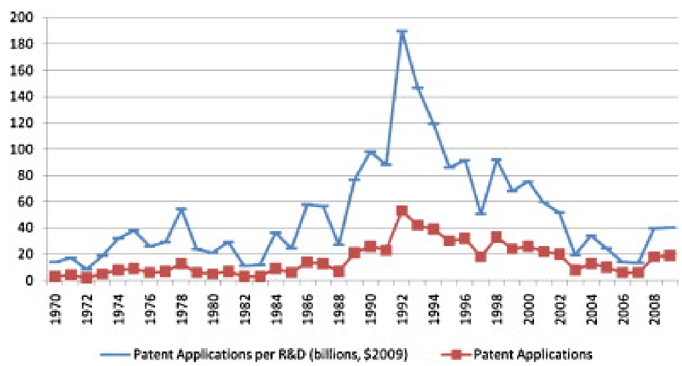

Fig. 2. Patent application trends at NIST: 1970–2009.

With respect to SNL patent applications and patent applications per $R&D, as shown in Fig. 1, activity remained constant and very low until 1985. Following 1985, there was a slight increase until 1990/1992. From 1990/1992 to 2000 there was a more substantial increase, and there has been a steady decline in patent applications and patent applications per $R&D since 2000.

Regarding the patenting activity trend at NIST in Fig. 2, there was a slight but erratic increase from 1970 to 1988, followed by a significant increase in patent applications and patent applications per $R&D until 1992. After 1992, both series declined steadily. Thus, at both SNL and NIST, the immediate post-Stevenson-Wydler Act period did not show significant patent application activity. The post-1986 Amendment period of increases appears to have been dampened by other events during the 1990s and later.

We estimated the following equations to assess the impact of selected legislative and institutional events on the SNL and NIST patent activities trends:

$$PATENTS = f(R\&D, \mathbf{X})$$

and

$$\frac{PATENTS}{R\&D} = f(\mathbf{X})$$

where PATENTS is the number of patent applications per year, R&D is the annual R&D budget of each laboratory (in billions $2009), PATENTS/R&D is patent applications per $R&D, and X is a vector of legislative and institutional events that we explore as possible covariates with each laboratory's patent activities over time.20

Two legislative events in vector X are common to all national laboratories. Each event is predicted in concept to have a positive impact on the incentive of laboratory scientists to apply for patents. The first is the passage of the Stevenson-Wydler Act of 1980 (henceforth, SWA), which, as discussed above, mandated technology transfer as an explicit mission of all national laboratories. The second legislative variable is the passage of the Federal Technology Transfer Act of 1986, FTTA, which provided a direct financial incentive to scientists to patent.21 However, although factors are not held constant, these conceptual predictions are not immediately evident in Fig. 1 and Fig. 2.

Vector X consists of two institutional events and a third control variable. The first variable, RampUp, relates to the approximate time when technology transfer efforts at each laboratory actually "ramped up" in response to the Stevenson-Wydler Act of 1980 and its 1986 Amendment, and the second variable, Mission, relates to periods during which the mission of each laboratory changed.

The Office of Intellectual Property Management, Alliances, and Licensing at SNL (i.e., the technology transfer office) ramped up in the mid-1990s. This does not mean that technology transfer activities were less important prior to, say, 1995. However, it does clearly indicate that additional resources were devoted to the internal laboratory infrastructure to promote technology transfer after that year.

At NIST, the Omnibus Trade and Competitiveness Act of 1988 not only changed the laboratory's name from NBS but also it broadened its research mission. As well, in that year there was a ramp-up in the sense that the Office of Research and Technology Assessment was formalized.

We conjecture that these institutional emphases on technology transfer, along with supporting resources, had a positive impact on the incentive of SNL and NIST scientists to patent and thus patenting activity will have increased afterwards, even holding constant the initial influence of the Stevenson-Wydler Act.

In addition to an increase in the allocation of internal resources devoted to technology transfer/commercialization, the mission of each laboratory, Mission, changed over time. This observation should not be interpreted positively or negatively, rather, mission changes are part of any research institution. We control for them, and we investigate them as possible covariates with patenting activity.

Production activities at SNL began in the early 1990s on a limited scale, but these activities were first seen in SNL's accounting budgets in 2004. In that year, SNL's accounting department began to separate production operating costs from research laboratory operating costs. Production operating costs averaged nearly 6 percent of total R&D costs over the 2004 through 2009 period.22 Diverting scientists from research to design, prototyping, and production could reduce the time available to undertake patentable research and thus patent applications could decrease over time.

There had long been an open policy toward scientists patenting and the directors had a broad interpretation of NIST's research mission. However, beginning in the early 1990s until about 2007 the various directors at NIST embraced a more narrow interpretation of NIST's mission and in response patenting was not as encouraged as it had been before or currently is.

Also in vector X is a variable to distinguish each laboratory within the pooled sample of data, LabDmy.23 This variable captures difference in the owner-controlled nature of each laboratory, among other things.

See Table 1 for summary definitions of these variables; see Table 2 and Table 3 for descriptive statistics on these variables for SNL and NIST, respectively.

Table 1. Definition of variables in Eq. (1).

Variables	Definition
PatAppl	Number of patent applications per year
R&D	R&D expenditures per year in billions ($2009)
PatAppl/R&D	Patent applications per billion of $R&D ($2009)
SWA	Binary variable denoting the enactment of the Stevenson-Wydler Act of 1980; equals 1 from 1980 through 2009, and 0 otherwise

Variables	Definition
FTTA	Binary variable denoting the enactment of the Federal Technology Transfer Act of 1986; equals 1 from 1986 through 2009, and 0 otherwise
RampUp	Binary variable denoting the start of internal efforts and internal resource allocation toward technology transfer; equals 1 from 1995 through 2009, and 0 otherwise for SNL, and equals 1 from 1988 through 2009, and 0 otherwise for NIST
Mission	Binary variable denoting a change in laboratory mission; equals 1 from 2004 through 2009, and 0 otherwise at SNL, and equals 1 from 1993 through 2007, and 0 otherwise at NIST
LabDmy	Binary variable; equals 1 for SNL and 0 for NIST

Notes: All annual data for SNL and NIST refer to the federal fiscal year. $R&D deflated by the GDP implicit price deflator, following Jankowski (1993).

Table 2. Descriptive statistics for the SNL variables (*n* = 40).

Variable	Mean	Std Dev	Min	Max
PatAppl[a]	69.100	76.010	0	201
R&D	1.679	0.344	0.911	2.135
PatAppl/*R&D*	36.340	40.381	0	119.153
SWA	0.750	0.439	0	1
FTTA	0.600	0.496	0	1
RampUp	0.350	0.483	0	1
Mission	0.150	0.362	0	1
LabDmy	1	0	1	1

a Patent application data were provided by the Office of Intellectual Property Management, Alliances, and Licensing.

Table 3. Descriptive statistics for the NIST variables (*n* = 40).

Variable	Mean	Std Dev	Min	Max
PatAppl[a]	15.475	12.233	0	53
R&D	0.304	0.075	0.212	0.472
PatAppl/*R&D*	50.399	39.738	8.384	189.724
SWA	0.750	0.439	0	1
FTTA	0.600	0.496	0	1
RampUp	0.550	0.504	0	1
Mission	0.350	0.483	0	1
LabDmy	0	0	0	0

a Patent application data were provided by the NIST Office of Technology Partnerships from 1973 through 2009. Patent application data prior to 1973 were obtained from the U.S. Patent and Trademark Office patent database http://patft.uspto.gov.

Regression estimates from Eq. (1) are presented in Table 4; results from Eq. (2) are presented in Table 5.24 Parameter estimates from both the pooled sample of SNL and NIST data and the separate samples for each laboratory are reported. Although the focal emphasis of each estimated equation is different—patent applications versus patent application intensity—there are two consistent finding from the regression results. Patenting activity in these two laboratories is primarily related to the financial incentives established through the Federal Technology Transfer Act and the availability of internal resources. The estimated coefficients on FTTA and RampUp are positive and statistically significant in all of the regressions.

Table 4. Negative binomial regression estimates of Eq. (1) (standard errors in parentheses).

Independent variable	(1)Pooled data	(2) SNL data	(3) NIST data
R&D	5.104 (0.737)*	1.405 (1.156)	−5.726 (1.481)*
SWA	−0.459 (0.327)	1.205 (0.950)	−0.082 (0.266)
FTTA	1.350 (0.328)*	3.303 (0.527)*	0.939 (0.295)*
RampUp	1.432 (0.255)*	1.430 (0.236)*	1.215 (0.279)*

Independent variable	(1)Pooled data	(2) SNL data	(3) NIST data
Mission	−1.477 (0.284)*	−0.525 (0.427)	−0.164 (0.186)
LabDmy	−7.016 (1.155)*	–	–
Intercept	−0.394 (0.238)***	−0.525 (0.427)	3.212 (0.388)*
Log likelihood	11965.825	10785.368	1213.989
Chi^2(df)	69.307	45.414	36.881
n	80	40	40

* Significant at .01-level.

**Significant at .05-level.

*** Significant at .10-level.

Table 5. Least-squares regression estimates of Eq. (2) (standard errors in parentheses).

Independent variable	(1) Pooled data	(2) SNL data	(3) NIST data
SWA	1.983 (11.316)	0.489 (7.105)	−6.460 (20.292)
FTTA	29.203 (11.649)**	25.304 (7.069)*	31.271 (20.716)
RampUp	39.384 (11.236)*	65.899 (6.522)*	35.822 (20.240)***
Mission	−20.476 (10.106)**	-16.607 (7.472)**	-35.430 (15.685)**
LabDmy	−8.660 (9.561)	–	–
Intercept	16.118 (9.441)***	0.249 (4.446)	26.324 (18.502)
R^2	0.791	0.939	0.684
D–W	1.999	1.927	1.928
n	80	40	40

* Significant at .01-level.

** Significant at .05-level.

*** Significant at .10-level.

The Federal Technology Transfer Act had a greater separate impact on patenting activity at SNL and NIST than did the Stevenson-Wydler Act. This is seen in columns (2) and (3) when Eqs. (1)

and (2) were estimated for each laboratory separately (although the estimated coefficient on FTTA in the NIST sample in Table 5 is significant only at the 0.15-level). In one sense, the statistical insignificance of the impact of the Stevenson-Wydler Act is not surprising. National laboratories have a history of transferring technology. DOE laboratories were transferring technology, albeit informally to university and industrial research partners through the Office of Science. NIST has long supported industry in the promulgation of standards, which is an explicit form of technology transfer.

The changed mission of both SNL and NIST had a negative and significant impact only on patent applications per $R&D. Individually, the coefficient on Mission from Eq. (1) was negative but not significant in columns (2) and (3) of Table 4, but it was negative and significant in columns (2) and (3) of Table 5.

4. Summary and policy conclusions

In this exploratory study, we analyzed patenting at SNL and NIST in the aftermath of several key legislative events. Our findings suggest that the enactment of the Stevenson-Wydler Act, which was similar in spirit to the Bayh-Dole Act, yet specifically targeted at national laboratories, was not sufficient to induce an increase in patent applications by scientists at SNL or NIST. However, it appears that the establishment of financial incentive systems, meaning the passage of the Federal Technology Transfer Act and the allocation of internal resources to support technology transfer, is correlated with an increase in such activity. The results also suggest that when the research mission of a national laboratory diverged from an emphasis on the creation of intellectual property toward other activities, patent applications declined.

The evidence presented in this paper also suggests that the enactment of Bayh-Dole like legislation was not sufficient to accelerate the rate of technological diffusion and commercialization from national labs to the marketplace. Even though there are major institutional and cultural differences between universities and national laboratories, as discussed in the introductory section of the paper, technology transfer offices at universities and national labs may have more in common than meets the eye. Therefore, it may be useful to apply lessons learned from the academic literature on university technology transfer offices and their ability to promote “university entrepreneurship” (see Siegel et al., 2007 and Rothermael et al., 2007 for comprehensive reviews of this literature).

This literature provides some important lessons for national laboratory administrators and other policymakers who wish to stimulate this activity. Before addressing the important aspects of incentives and culture, the director of the national laboratory or the federal agency that controls the laboratory must first make clear that technology commercialization is a key strategic priority of the institution. This strategic choice should be reflected in resource allocation patterns; e.g., hiring more individuals with strong technical and commercial backgrounds to staff the technology transfer office.

The personnel aspect of technology transfer may be even more vital at a national laboratory than at the university, given the vast growth in university–industry partnerships and the fact that universities tend to be more affected by market forces. It has been difficult to attract and retain technology transfer office personnel with the appropriate skill sets to facilitate commercialization. Traditionally, there is an emphasis in technology transfer offices on legal skills, with an eye toward protecting the laboratory's intellectual property portfolio.

In recent years, universities have been placing a stronger emphasis on the entrepreneurial dimension of technology commercialization, which has led to a substantial increase in the number of university-based startups. Perhaps this channel of commercialization needs to be stressed more at national labs. That is, an expansion of technology commercialization will require the creation and development of start-ups, which means that technology transfer office employees must also be adept at opportunity recognition, marketing, finance, and other aspects of commercialization. They also need to be adept at interacting with venture capitalists and angel investors.

In conclusion, we hope that this study stimulates additional research on the antecedents and consequences of commercialization efforts at national laboratories, both in the United States and other industrialized nations. Given the importance of these laboratories to a national innovation system, and hence to an economy, these institutions deserve more attention in the academic literature.

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Footnotes

1 Public Law 96-517, Amendments to the Patent and Trademark Act, passed on December 12, 1980, is commonly referred to as the Bayh-Dole Act. For an overview of the enactment of the Act, see Stevens (2004) and Schacht, 2000 and Schacht, 2009a.

2 See Siegel et al., 2003a and Siegel et al., 2003b, Mowery (2004), Lerner (2005), Mowery and Sampat (2005), and several government studies summarized in Schacht (2009a).

3 Link et al. (2007) have demonstrated that, even with revenue sharing, not all patented inventions leave the university through its technology transfer office. See Siegel et al. (2007) for a summary of the burgeoning literature on assessing the "performance" of technology transfer offices and other commercialization efforts at universities.

4 Public Law 96-480 was passed on October 21, 1980.

5 The only exception was the National Aeronautics and Space Administration (Schacht, 2009b). However, many national laboratories informally transferred their technology to host agencies. This was especially true of the Department of Defense (DoD) laboratories, which were operated individually by each of the separate military branches. From an historical perspective, one might argue that the Hatch Act of 1887, which created agricultural experiment stations, established an explicit technology transfer mission.

6 Public Law 99-502 was passed on October 20, 1986. The Federal Technology Transfer Act allowed the director of any government-owned government-operated (GOGO) laboratory to enter into a Cooperative Research and Development Agreement (CRADA) with industry or with universities for the transfer of federally owned or federally originated technologies. GOCO laboratories were granted the authority to enter into CRADA agreements under the 1990 Defense Authorization Act (Public Law 101-189) (Schacht, 2009b).

7 The Federal Laboratory Consortium (FLC) was established with the assistance of the Department of Defense in the early 1970s for the purpose of coordinating the transfer of

technology to local and state governments. The Federal Technology Transfer Act provided a Congressional mandate for these activities. See, Metcalf (1994) and Schacht (2009b) for greater institutional detail.

8 There has also been qualitative studies of startup activity resulting from activity at national laboratories (Carayannis et al., 1998).

9 See Toregas (2004) for a discussion of NASA's innovation disclosures.

10 In addition to the current 2800 employees at NIST, there are about 1800 visiting scientists and 1400 affiliated field agent.

11 The systematic collection of data on university patenting, licensing, and startup creation by the Association of University Technology Managers (AUTM) and associated university rankings has focused attention on these metrics of performance (Siegel et al., 2003a and Siegel et al., 2003b).

12 This early history draws directly from Ullrich (1999) and Sullivan (2010). Also, see Westwick (2003).

13 Sandia means "watermelon" in Spanish. The mountains east of Albuquerque are called the Sandia Mountains because they take on a color similar to the inside of a watermelon in the afternoon sun. See, http://www.sandia.gov/about/history/faq/faq8.html.

14 SNL is one of the 18 major DOE laboratories. See, http://www.energy.gov/organization/labs-techcenters.htm.

15 See, http://www.sandia.gov/mission/.

16 Until 1993, SNL was managed by AT&T. AT&T assumed management responsibilities from the University of California at the request of President Truman.

17 This early history draws from Link and Link (2009). A standard is a prescribed set of rules, conditions, or requirements concerning: definitions of terms; classification of components; specification of materials, their performance, and their operations; and delineation of procedures, and measurement of quantity and quality in describing materials, products, systems, services, or practices.

18 Public Law 100-418 was passed on August 23, 1988.

19 These data were graciously provided by SNL and NIST. No lag between R&D spending and patent application underlies the $R&D data in Fig. 1 and Fig. 2.

20 Eq. (1) is consistent with the literature on R&D production functions (Griliches, 1998) and a similar model has been applied to patenting and other forms of research commercialization by firms located on university research parks (Siegel et al., 2003b).

21 For a more detailed discussion, see GAO, 1992 and GAO, 1994.

22 SNL's production activities began in 1993 when it was assigned responsibility for the production of neutron tubes and neutron generators (see, http://www.sandia.gov/media/neutron.htm). Previously, these weapons elements were produced at the Pinellas Plant in Florida, which is part of DOE's weapon's complex (see, http://www.em.doe.gov/bemr/BEMRSites/pipl.aspx). Production began in 1996. More recently, in 2007 SNL opened the 400,000 square foot Microsystems Engineering Sciences and Applications (MESA) Complex to produce functional, robust, integrated microsystems (see, http://www.sandia.gov/SAI/Manufacturingmaterials.htm).

23 Of course, the portfolio of patentable research at both laboratories likely changed over time. Absent a way to account for this, we assume it is captured in the error terms.

24 Other specifications were also considered including lagged and non-linear values of R&D. In general, the conclusions from these alternative specifications are not different from what is presented in Table 4 and Table 5. All results are available from the authors.