U.S. federal laboratories and their research partners: a quantitative case study

By: Chuchu Chen, Albert N. Link, and Zachary T. Oliver

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Abstract:

The Stevenson–Wydler Technology Innovation Act of 1980 made explicit the technology transfer responsibilities of U.S. Federal laboratories. The Federal Technology Transfer Act of 1986 and the National Competitiveness Technology Transfer Act of 1989 further enhanced the technology transfer activities of laboratories by permitting Cooperative Research and Development Agreements (CRADAs). However, very little is known about the characteristics of CRADA activity in Federal laboratories. Using a new, robust dataset of CRADA activity at the National Institute of Standards and Technology (NIST), we describe research partnerships over the years 1978 through 2014, and we explore several research questions. When did the Federal Technology Transfer Act have an impact on CRADA activity at NIST? Is CRADA activity at NIST a cyclical phenomenon? At what frequency do private sector establishments engage in CRADA activity with NIST? We find suggestive evidence that the Federal Technology Transfer Act began to influence NIST's CRADA activity within 2–3 years after its passage, and we find that CRADA activity moves with the business cycle. We also find that most establishments that were engaged in CRADA activity were engaged only once over this time period; it was only the larger establishments that continued to engage in CRADAs with NIST. We speculate about the implications of these findings, and we suggest a broader research agenda into CRADA activity in Federal laboratories.

Keywords: CRADA | program management | federal laboratory | NIST | technology | Schumpeterian hypothesis | evaluation | assessment

Article:

Introduction

The Stevenson–Wydler Technology Innovation Act of 1980 (Public Law 96-480) made explicit the technology transfer responsibilities of U.S. Federal laboratories. To further enhance the ability of the laboratories to transfer their technologies, the Federal Technology Transfer Act of 1986 (Public Law 99-502) facilitated technology transfer by permitting the laboratories to enter into Cooperative Research and Development Agreements (CRADAs) with public sector and private sector organizations.

A CRADA, according to the Federal Technology Transfer Act of 1986, is[1]:

> … 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.

CRADAs, as a technology transfer mechanism, are potentially advantageous to both parties. As outlined in the *Technology Transfer Desk Reference* (Federal Laboratory Consortium for Technology Transfer 2013, pp. 33–34), CRADAs:

> … provide federal laboratories with an extremely flexible vehicle to facilitate the transfer of commercially useful technologies from federal laboratories to the nonfederal sector. … The establishment of cooperative R&D efforts through a CRADA has perhaps the greatest possibility for long-term payoff of any technology transfer mechanism. An intimate working relationship between federal and commercial researchers will allow the federal side to understand commercial needs and allow ideas from the commercial sector to flow into federal laboratories.

CRADAs also provide the partnering organizations an opportunity to commercialize technologies resulting from joint R&D, and CRADAs provide a vehicle for laboratory scientists to receive a percentage of the royalties from any resulting licensed technologies.[2]

The empirical literature on technology transfer mechanisms in Federal laboratories is limited, perhaps due to inaccessibility to agency-specific data. Much of the empirical literature on CRADA activity at Federal laboratories has been case based. This literature dates to the early 1990s, shortly after the passage of the Federal Technology Transfer Act of 1986. These case studies focused primarily on Department of Defense (DoD) and Department of Energy (DOE) laboratories and the activities therein. Wu (1994) and Franza et al. (2012) provide excellent examples of successful DoD CRADAs. The scholarship of Feldman (1990), Sink and Easley (1994), Ham and Mowery (1995, 1998), Prosser (1995), and Mowery (2003) typify the DOE case studies. Among this early body of literature, Bozeman and Papadakis (1995) were among the few who constructed original databases of Federal laboratory technology transfer activity. Their study identified 229 Federal laboratories with company collaborative research projects (1989–1993). Only 26% of these collaborations were undertaken through a CRADA arrangement. The extant legislation-related empirical literature there is about Federal laboratories has focused primarily on patenting activity (e.g., Jaffe et al. 1998; Jaffe and Lerner 2001; Link et al. 2011).

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[1] Title 15, Chapter 63 § 3710a of the U.S. Code gives agencies authority to enter into CRADA agreements.

[2] Although the FLC's *Desk Reference* emphasizes the benefits from technology transfer, not all agree about their advantages. Bodde (1993), for example, overviewed some of the early general problems with CRADAs in Federal laboratories. The Office of Technology Assessment (1993) reported specific examples of problems with CRADAs that were focused on defense conversion. See also, Shama (1992).

CRADA activity, as emphasized in the Federal Technology Transfer Act of 1986, is a technology transfer mechanism that has been understudied within a given agency or laboratory at either a longitudinal level or a disaggregated level. This paper contributes to the technology transfer literature through its detailed characterization of CRADA activity at one Federal Laboratory—the National Institute of Standards and Technology (NIST) within the U.S. Department of Commerce. As noted just above, the extant literature on CRADAs is thin; this paper is arguably the first to examine systematically, albeit descriptively and in an exploratory manner, detailed CRADA activity at a Federal laboratory. And, in addition to this paper's description of NIST CRADAs, it offers an initial glimpse at the timing of the effectiveness of the Federal Technology Transfer Act.

Our focus on NIST is pragmatic on several counts. First, the Federal Technology Transfer Act established the Federal Laboratory Consortium (FLC) for Technology Transfer, and the National Bureau of Standards (NBS, which later became NIST) acts as the host agency. A charge of the FLC was then and still is now to increase awareness of technology transfer activities in Federal laboratories. Second, NIST is the agency that coordinates the annual reporting to the Office of the President and to Congress of all agencies technology transfer activities.[3] And third, President Barack Obama's 2011 Presidential Memorandum—Accelerating Technology Transfer and Commercialization of Federal Research in Support of High-Growth Businesses (discussed below) called for all agencies to compile their technology transfer metrics, and NIST collects and reports expanded metrics with the Interagency Workgroup on Technology Transfer in annual reports.[4,5]

The remainder of this paper is outlined as follows. In section "A legislative overview", we provide a brief legislative overview of the Stevenson–Wydler Act and the Federal Technology Transfer Act. In section "NIST and NIST CRADA activity", we briefly describe the history and research mission of NIST and its partnership activity from 1978 through 2014. We also compare NIST's CRADA activity to that of other Federal laboratories. In section "Empirical analysis of the research questions", we describe CRADA activity at NIST by investigating empirically three research questions. When did the Federal Technology Transfer Act have an impact on CRADA activity at NIST? Is CRADA activity at NIST a cyclical phenomenon? At what frequency do private-sector establishments engage in CRADA activity with NIST? Because of the exploratory nature of our analysis, and because of limited data to use as controls, our statistical models are parsimonious in their structure. "Implications of our findings and an agenda for future research" section concludes the paper with summary remarks about the program management implications of our findings, and we suggest elements of a possible agenda for future research.

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[3] See, https://www.nist.gov/tpo/federal-laboratory-interagency-technology-transfer-summary-reports.
[4] The Interagency Workgroup on Technology Transfer (IAWGTT) is comprised of a technology transfer representative from each involved agency. Its purpose is to discuss best practices in technology transfer from Federal agencies. It is coordinated by the director of the Technology Partnership Office at NIST.
[5] It has long been a problem for academic researchers to obtain data from Federal laboratories. That fact is perhaps the reason the related body of literature on Federal laboratory technology transfer is thin in comparison to the body of literature on academic technology transfer from universities. For example, Link et al. (2011) reported that they were only able to obtain longitudinal patent data from two Federal laboratories.

A legislative overview

On October 21, 1980, the U.S. Congress passed the Stevenson–Wydler Technology Innovation Act of 1980. This Act clearly states Congress' belief that research cooperation is critical for the nation to enhance its technology and innovation base[6]:

> Cooperation among academia, Federal laboratories, labor, and industry, in such forms as … joint research projects … should be renewed, expanded, and strengthened.

To enhance the technology transfer mission of Federal laboratories, Congress amended the Stevenson–Wydler Act of 1980 on October 20, 1986, with the passage of the Federal Technology Transfer Act of 1986. Therein is stated[7,8]:

> Each Federal agency may permit the director of any of its Government-operated Federal laboratories to enter into cooperative research and development agreements on behalf of such agency.

NIST and NIST CRADA activity

A brief history of NIST

NIST is the U.S. standards agency; it specializes in the field of measurement science (metrology). 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.[9]

Following a long history of U.S. leaders calling for uniformity in science, traceable at least to the several formal proposals for a Department of Science in the early 1880s, it was inevitable that a

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[6] The Stevenson–Wydler Act also makes clear that it is the responsibility of each Federal laboratory to establish an Office of Research and Technology Applications to transfer its technology to those organizations that will benefit.
[7] The Federal Technology Transfer Act established the FLC within the NBS, which later became NIST. The FLC would, according to the Act: "develop and (with the consent of the Federal laboratory concerned) administer techniques, training courses, and materials concerning technology transfer to increase the awareness of Federal laboratory employees regarding the commercial potential of laboratory technology and innovations …" See, Metcalf (1994). Brand (2003) also discussed the early role of the FLC in encouraging technology transfer from the Federal laboratories.
[8] The Federal Technology Transfer Act was clear that Government-Owned, Government-Operated laboratories (GOGOs) could enter into CRADAs, but the Act was not specific to Government-Owned, Contractor-Operated laboratories (GOCOs). The National Competitiveness Technology Transfer Act of 1989 (Public Law 101-189, Section 3131) amended the Stevenson–Wydler Act of 1980 to authorize GOCOs to enter into CRADAs. See, Kerrigan and Brasco (2002).
[9] The concept of the government's involvement in standards traces to the Articles of Confederation signed on July 9, 1778. This responsibility was reiterated in Article 1, § 8 of the Constitution of the United States: "The Congress shall have power … [t]o coin money, regulate the value thereof, and of foreign coin, and fix the standard of weights and measures …".

standards laboratory would need to be established.[10] Finally, on March 3, 1901, the NBS was established within the Department of the Treasury.[11]

In the post-World War I years, the NBS'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. After World War II, significant attention and resources were given to the activities of the Bureau. In particular, it was charged to establish standards for electrical and photometric measurements. Then, in 1956, the NBS moved from Washington, D.C. to Gaithersburg, Maryland, and its responsibilities were transferred to the NIST when NBS was so renamed under the guidelines of the Omnibus Trade and Competitiveness Act of 1988.

NIST's stated mission is[12]

> … to promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life.

And, NIST's value statement is that it will be the world's leader in creating critical measurement solutions and promoting equitable standards. The efforts at NIST stimulate innovation, foster industrial competitiveness, and improve the quality of life.

NIST's CRADA activity

On October 28, 2011, President Barack Obama issued a Presidential Memorandum—Accelerating Technology Transfer and Commercialization of Federal Research in Support of High-Growth Businesses:

> I direct that … [a]gencies with Federal laboratories shall develop plans that establish performance goals to increase the number and pace of effective technology transfer and commercialization activities in partnership with non-federal entities…

NIST, as did other Federal agencies, responded to the Presidential Memorandum of 2011, stating that it would expand the collection of its technology transfer metrics, especially the collection of CRADA activity, and this effort complements the overall mission of NIST:

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[10] The political force for this laboratory came in 1900 through Lyman Gage, then Secretary of the Treasury under President William McKinley. Gage's original plan was for the Office of Standard Weights and Measures to be recognized as a separate agency called the National Standardizing Bureau. This Bureau would maintain custody of standards, compare standards, construct standards, test standards, and resolve problems in connection with standards.

[11] In 1903, the Department of Commerce and Labor was established and the NBS was transferred from the Department of the Treasury to the Department of Commerce and Labor. Then, in 1913, when the Department of Labor was established as a separate entity, the Bureau was formally housed in the Department of Commerce.

[12] See, https://www.nist.gov/about-nist/our-organization/mission-vision-values.

> NIST is expanding the metrics collected for technology transfer. Traditionally, the metrics reported are counts of activities, such as the number of Cooperative Research and Development Agreements (CRADAs), with anecdotal examples of public benefit.

A complete history of CRADA activity at NIST was thus assembled with the assistance of its Technology Partnership Office, and these historical data form the database that is described herein. Data were collected on the 3431 traditional and non-traditional fully executed CRADAs and partnerships during CYs 1978 through 2014.[13]

While these data arguably represent the most complete description of CRADA activity at any Federal laboratory, it should be pointed out that NIST is not the most CRADA-intensive Federal laboratory. As reported in *Federal Laboratory Technology Transfer: Fiscal Year 2014* (NIST 2016), there were across the laboratories in all Federal agencies, 32,073 active traditional and non-traditional CRADAs and partnerships in FY 2014. Note that NIST, within the Department of Commerce, was involved in only 10% of these.[14] The laboratories at the Department of Agriculture were responsible for 54% of them. Note too, 71% of NIST's total R&D budget went to laboratories and intramural research.[15] That percentage is exceeded only by DOE's laboratories with 72%, the Department of Interior's laboratories with 88%, and the Department of Veteran Affairs' laboratories with 100%. Regardless of the comparative metrics, our study of CRADAs at NIST should be viewed only as a case study of one specific Federal laboratory.

Of NIST's 3431 CRADAs, the year in which a CRADA was initially executed was available for only 2465 CRADAs (72%).[16] Table 1 shows the number of traditional and non-traditional CRADAs per year; Fig. 1 illustrates these data. A traditional or bilateral CRADA is one that involves a collaborative research and development project by NIST and non-Federal partners. Non-traditional CRADAs also involve non-Federal partners; they are used for special purposes which partners cannot do internally such as materials transfers, calibrations of specialized equipment, or seeking technical assistance that involves or produces information that warrants protection from disclosure.[17]

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[13] It is important to emphasize that CRADAs by name did not exist until the passage of the Federal Technology Transfer Act of 1986, as discussed above. However, prior to 1986, NIST did engage in research partnership relationships and those are noted in the data discussed below in Table 1 beginning in 1978. One will see in Table 1 that there were 4 such partnership prior to 1986. For simplicity, we titled the columns in Table 1 as representing CRADAs; and for simplicity we refer to the total dataset as referring to CRADAs. Also, it is important to note that many non-traditional CRADAs involve calibrations, an activity unique to NIST.
[14] The technology transfer activity in the other laboratories in the Department of Commence (i.e., the National Oceanic and Atmospheric Administration (NOAA), and the National Telecommunications and Information Administration (NTIA)'s Institute for Telecommunication Sciences (ITS)) is minimal in comparison to the activities at NIST.
[15] For an in-depth study of NIST's intramural research see, Link and Scott (2005).
[16] Ideally, we would like to compare this sample of 2465 CRADAs to the NIST population of 3431 CRADAs in several dimensions. However, enterprise information in both this sample and the population is not reported in D&B Hoovers (see below) and thus even a descriptive analysis of the representativeness of the sample of 2465 CRADAs is not possible.
[17] Selected examples of NIST CRADAs are in NIST's Annual Reports to the Office of Management and Budget on Technology Transfer; see, https://www.nist.gov/tpo/department-commerce.

Table 1. Executed CRADAs at NIST, 1978–2014 (n = 2465).

Year	Total new CRADAs executed	New traditional CRADAs executed	New non-traditional CRADAs executed
1978	1	1	0
1979–1983	0	0	0
1984	1	1	0
1985	2	1	1
1986	0	0	0
1987	0	0	0
1988	19	18	1
1989	54	44	10
1990	60	40	20
1991	69	29	40
1992	99	64	35
1993	141	92	49
1994	143	107	36
1995	82	46	36
1996	233	50	183
1997	96	59	37
1998	88	31	57
1999	83	31	52
2000	97	25	72
2001	122	9	113
2002	59	10	49
2003	24	11	13
2004	19	11	8
2005	57	10	47
2006	105	11	94
2007	25	8	17
2008	39	19	20
2009	52	9	43
2010	66	13	53
2011	86	13	73
2012	118	18	100
2013	181	24	157
2014	244	53	191
Total	2465	858	1607

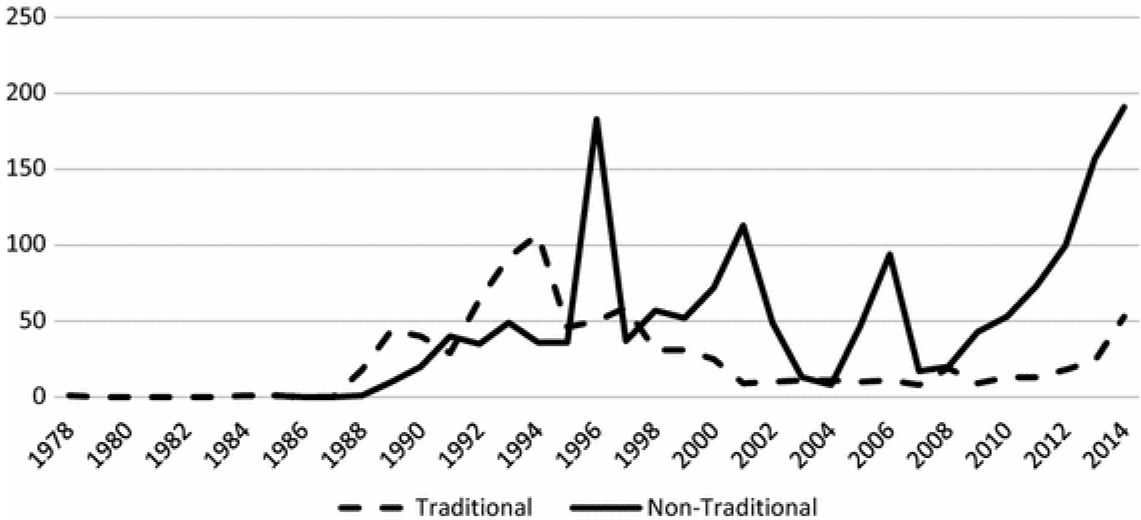

Fig. 1. New traditional and non-traditional CRADAs executed at NIST, 1978–2014 (n = 2465). *Source*: Table 1

Empirical analysis of the research questions

Did the federal technology transfer act have an impact on CRADAs at NIST?

Visually, it appears from Fig. 1 that the increase in CRADA activity, in total and by type, began soon after the passage of the Technology Transfer Act of 1986, as expected.

To explore in more detail when the impact of the Federal Technology Transfer Act had an effect on CRADA activity at NIST, we tested for a statistical break in the yearly change in the total number of CRADAs executed each year. Our basic model is:

$$\text{TotalCRADAs} = f(\text{Year}, \varepsilon) \tag{1}$$

where TotalCRADAs is the total number of new CRADAs at NIST each year as reported in the second column in Table 1, Year is an annual time trend, and ε is an error term with properties that vary based on the specification of Eq. (1). Using a linear specification for comparative purposes, and a Poisson and negative binominal specification because the dependent variable is a count variable, we estimated that annual change in CRADA activity went from being statistically equal to zero to being positive and statistically significant (at the 0.05-level of significance) at a point between years 1988 and 1989, as expected from visually inspecting Fig. 1. The statistical breakpoint is 1989 in the linear and negative binomial specifications, and it is 1988 in the Poisson specification.[18] Thus, the impact of the Federal Technology Transfer Act was almost immediate.

Is CRADA activity at NIST a cyclical phenomenon?

To explore over time the cyclical nature of NIST CRADA activity, we considered the model:

[18] These results are available on request from the authors.

$$\text{TotalCRADAs} = f(\text{lnGDP}, \varepsilon) \quad (2)$$

where lnGDP is the natural logarithm of gross domestic product (GDP) in billions ($2009); the logarithmic transformation is used to account for the skewness of that variable. Descriptive statistics on these variables and the regression results from specifications of Eq. (2) are in Tables 2 and 3, respectively. GDP over time approximates the business cycle. However, between 1978 and 2014 there were a number of specific economic events which might be relevant to CRADA activity. Of course, there was the Stevenson–Wydler Act of 1980 and the Federal Technology Transfer Act of 1986. In addition, the U.S. economy experienced downturns in 1991, 2001, and in the Great Recession of 2008–2009. Still, to explore the cyclical nature of NIST's CRADA activity, we view GDP as an appropriate indicator of business cycles over time.

Table 2. Variables used to estimate total number of CRADAs with NIST by private sector partners (n = 37)

Variable	**Definition**		
TotalCRADAs	Total number of new CRADAs executed at NIST each year, 1978 through 2014		
GDP	Gross domestic product in billions ($2009)		
Variable	**Mean**	**SD**	**Range**
TotalCRADAs	66.62	64.17	0–244
GDP	10,925.4	3232.0	6267.2–16,013.3

Table 3. Regression results on total number of CRADAs at NIST (n = 37)

Variable	**Linear model TotalCRADAs**	**Poisson model TotalCRADAs**	**Negative binominal model TotalCRADAs**
lnGDP	114.13***	1.97	3.94
	(25.73)	(0.484)	(1.24)
		[110.87]***	[193.68]***
Constant	− 989.50	− 14.16***	− 32.54***
	(233.43)	(4.59)	(11.53)
$F(1, 35)$	19.68	–	–
Wald Chi^2 (1)	–	16.47***	10.12***
Log likelihood	–	− 928.88	− 179.28

Robust standard errors in parentheses. Marginal effects are in brackets; standard errors calculated using the delta method

***$p < 0.01$

The regression results from Eq. (2) are in Table 3. The Poisson model and the negative binominal model are more appropriate for count data; the linear model is shown for comparative purposes. The regression results suggest that CRADA activity at NIST is procyclical as evidenced by the positive and statistically significant coefficient on lnGDP.[19] One possible interpretation of this finding is that private sector firms have more flexibility during an upturn in the business cycle to allocate funding to collaborative research. If this interpretation is correct, it might suggest that CRADA activity complements in-house R&D.

[19] The same result holds if the total number of CRADAs is disaggregated between traditional and non-traditional CRADAs as in Table 1. These results are available from the authors on request.

At what frequency do private sector establishments engage in CRADA activity with NIST?

To explore in greater detail characteristics of NIST's CRADA partners, the observations in the sampling population of 2465 CRADAs were matched with establishment information from D&B Hoovers primarily based on an industry identifier and an establishment address.[20] Through that matching process, 1891 CRADAs could uniquely be linked to a specific NAICS code and to the current employment size of the establishment partner in the CRADA.[21]

Table 4. Executed CRADAs at NIST by category of partners, 1978–2014 (n = 1891).

Year	Total new CRADAs executed	Private sector	Academic sector	Government sector
1978	1	1	0	0
1979–1983	0	0	0	0
1984	1	1	0	0
1985	1	1	0	0
1986	0	0	0	0
1987	0	0	0	0
1988	9	9	0	0
1989	36	35	0	1
1990	38	38	0	0
1991	47	43	1	3
1992	74	64	10	0
1993	100	85	12	3
1994	96	87	7	2
1995	51	46	4	1
1996	184	116	64	4
1997	68	56	12	0
1998	78	45	30	3
1999	65	40	22	3
2000	81	44	35	2
2001	114	36	66	12
2002	48	8	38	2
2003	18	17	1	0
2004	19	18	1	0
2005	41	40	1	0
2006	77	76	1	0
2007	23	18	5	0
2008	32	28	3	1
2009	45	31	12	2
2010	57	53	4	0
2011	65	58	4	3
2012	100	74	22	4
2013	146	118	21	7
2014	176	141	29	6
Total	1891	1427	405	59

[20] See, http://www.hoovers.com/.
[21] Hoovers only reports the current (2017) number of employees, and we use that number regardless of the year that the CRADA was formed.

Using NAICS codes, we grouped each CRADA partner into one of three categories for descriptive purposes: private sector, academic sector, or government sector. Just over 75% of the CRADAs were with private sector firms (n = 1427), followed by about 21% with colleges and universities in the academic sector (n = 405), followed by slightly more than 3% with agencies from the government sector (n = 59). The underlying data, by year, for this categorization are in Table 4. With a few exceptions in early 2000, the number of CRADAs with private sector establishments has been greater than with colleges and universities from the academic sector. Figure 2 illustrates the data in Table 4. The figure suggests that private-sector CRADA activity also began to increase shortly after the passage of the Technology Transfer Act of 1986.

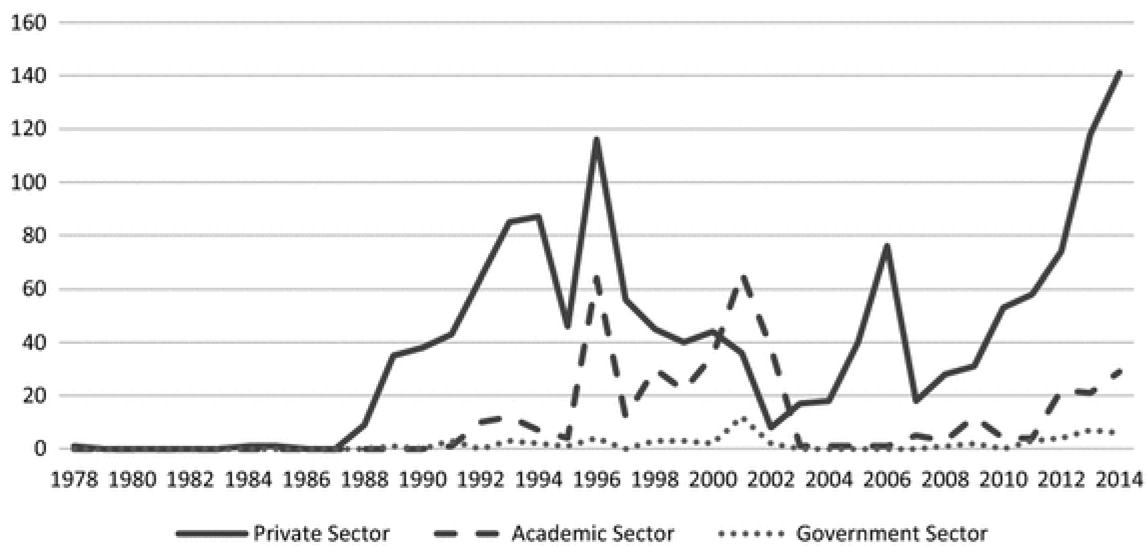

Fig. 2. Executed CRADAs at NIST, by category of partner, 1978–2014 (n = 1891).
Source: Table 4

We were able to group each private-sector CRADA establishment into a unique 2-digit industry from the NAICS codes in Hoovers, as shown in Table 5.[22] A total of 730 of the 1891 CRADAs, or nearly 39%, were in the manufacturing sector,[23] followed by nearly 21% in the educational services sector (i.e., academic sector) (n = 405), and 21% in the professional, scientific, and technical services (n = 389). Just over 3% were in public administration (i.e., government sector) (n = 59).

Some private-sector (i.e., non-academic and non-government sector) establishments were involved in more than one CRADA at NIST from 1978 through 2014. A total of 910 different private sector establishments were engaged in the 1427 private-sector CRADAs with NIST over the time period of study. A total of 691 of the 910 firms were involved in only 1 CRADA, 124 firms were involved in 2 CRADAs, 37 firms were involved in 3 CRADAs, and 58 firms were involved in 4 or more CRADAs over the years 1978 through 2014.

[22] NAICS codes from Hoovers do not change over time.
[23] The preponderance of CRADAs in the manufacturing sector is perhaps the results of non-traditional CRADAs, such as calibrations, with manufacturing firms.

Table 5. Distribution of CRADAs by 2-digit NAICS codes, 1978–2014 (n = 1891).

Sectors (listed by number of CRADAs)	
31–33: Manufacturing	730
61: Educational services (universities)	405
54: Professional, scientific, and technical services	389
42: Wholesale trade	66
51: Information	65
92: Public administration	59
21: Mining, quarrying, and oil and gas extraction	31
62: Health care and social assistance	30
56: Administrative and support and waste management and remediation services	28
44: Retail trade	26
81: Other services (except public administration)	24
71: Arts, entertainment, and recreation	9
23: Construction	7
22: Utilities	6
99: Unclassified	5
52: Finance and insurance	4
55: Management of companies and enterprises	3
48: Transportation	2
45: Retail trade	1
49: Warehousing	1
Total	1891

To investigate the frequency with which private-sector establishments engaged in CRADA activity with NIST, we focused on establishment size.[24] Our investigation fits more generally in the literature initiated by Nelson (1986) and Freeman (1987) on the hypothesized complementary relationship between firms and institutions, such as government agencies.

In a broad sense, our investigation also relates to a test of the Schumpeterian hypothesis which posits that large establishments will be more effective than small establishments in generating technological advancements. While scholars have investigated the size-to-R&D relationship for decades (e,g., Link 1980; Baldwin and Scott 1987; Cohen and Klepper 1996; Cohen et al. 1987; Cohen 2010), the extant literature that is related to technology transfer has focused primarily on the size-to-patenting relationship which was initiated by Scherer (1983) and Pakes and Griliches (1984), and which has been reviewed by Cohen (2010). The size-to-frequency of CRADA activity is a characteristics of CRADA activity that has not yet been explored; as well, it is a dimension of Schumpeter's hypothesis that has yet to be investigated.

To explore this variant of the Schumpeterian hypothesis, we looked at the employment size of establishments that were involved in CRADA activity with NIST. On the one hand, smaller establishments might have a greater tendency to collaborate with NIST (or any Federal laboratory) through a CRADA because they do not have sufficient internal technical resources to pursue their research agenda on their own. If this is the case, then smaller establishments are likely using CRADAs as a substitute for internal R&D capabilities. On the other hand, larger

[24] Our prior is that employment is a more meaningful measure of size for establishments in the private sector than for organizations in the academic sector or agencies in the government sector.

establishments might have a greater tendency to collaborate with NIST (or any Federal laboratory) through a CRADA because CRADAs involve contractual relationships and larger establishments are more likely to have the capability to deal with such legal matters. Also, because of the complex research nature of many CRADAs, an establishment might need internal capabilities or absorptive capacity to effectively make use of such a collaboration. If this is the case, then larger establishments are likely using CRADAs to complement their internal research capabilities.

Table 6 defines the variables used to explore the question of inter-establishment differences in the extent of CRADA activity at NIST, and it reports descriptive statistics on the variables. On average, the 910 private sector establishments have been involved in 1.6 CRADAs over the years 1978 through 2014. On average, the current employment size of the 910 establishments is 436. Nearly 50% of the 910 enterprises come from the manufacturing sector, and another 26% from the professional, scientific, and technical services sector.

Table 6. Variables used to estimate number of CRADAs with NIST by private sector partners over the 1978–2014 period (n = 910)

Variable	Definition
Number	Number of executed CRADAs by each private sector firm that had at least 1 CRADA with NIST, 1978 through 2014
Employment	Number of employees in the private sector establishments as reported in D&B Hoovers for 2017
Manufacturing	= 1 if the establishment is in the manufacturing sector; 0 otherwise
Professional	= 1 if the establishment is in the professional, scientific, and technical services sector; 0 otherwise

Variable	Mean	SD	Range
Number	1.57	1.67	1–20
Employment	435.56	1626.24	1–28,000
Manufacturing	0.497	0.500	0/1
Professional	0.262	0.440	0/1

Regarding the empirical analysis, the size-to-CRADA relationship was investigated using absolute numbers and their natural logarithm in an effort to mirror specifications that have been used in the literature. Alternative specifications of the underlying model were also investigated. While the Poisson model and the negative binomial model are more appropriate for count data, we included in Table 7 the results from linear models as points of comparison. The count models fit the data better than the linear models, as expected, and the logarithmic specifications fit the data better than the non-logarithmic specifications. While the results in Table 7 support the Schumpeterian hypothesis, as we have defined it, the magnitude of the size effect is small. From the calculated marginal effect in the double logarithmic count models, a 100% increase in employment is associated with just over three additional CRADAs. All of the specifications are significant.

Our finding that larger private-sector firms are engaged more frequently in NIST CRADAs is of academic interest when presented as a new interpretation of the Schumpeterian hypothesis. However, our finding might possibly have program management implications as well. There is a rich literature that traces to Acs and Audretsch (1987) that shows that small firms are more innovative, relative to their size, than large firms. Perhaps if NIST, or any Federal laboratory, focused on CRADA activity with even smaller firms, all else held constant, the net social benefits from their technology transfer efforts might be greater than whatever they currently are (and the issue of whatever they currently are is discussed in the following section "Implications of our findings and an agenda for future research").[25]

Table 7. Regression results on number of CRADAs with NIST by private sector partners ($n = 910$)

Variable	Linear model Number	Linear model ln Number	Poisson model Number	Poisson model ln Number	Negative binominal model Number	Negative binominal model ln Number
Employment	0.00007	–	0.00004*	–	0.00004*	–
	(0.00005)		(0.00002)		(0.00002)	
			[0.00005]*		[0.00006]*	
ln(Employment)	–	0.039***	–	0.153***	–	0.152***
		(0.009)		(0.032)		(0.035)
				[0.035]***		[0.035]***
Manufacturing	0.204	0.056	0.139	0.292	0.136	0.291
	(0.135)	(0.038)	(0.092)	(0.188)	(0.062)	(0.189)
Professional	0.239	0.096**	0.160	0.440**	0.158	0.438**
	(0.158)	(0.046)	(0.0105)	(0.212)	(0.105)	(0.213)
Constant	1.37***	0.043	0.320***	− 2.32***	0.321***	− 2.31***
	(0.112)	(0.043)	(0.081)	(0.231)	(0.080)	(0.232)
$F(3, 906)$	1.51	7.52***	–	–	–	–
Wald Chi^2 (3)	–	–	5.22	24.89***	5.09	24.77***
Log likelihood	–	–	− 1419.17	− 547.25	− 1392.50	− 547.19

Robust standard errors in parentheses. Marginal effects are in brackets; standard errors calculated using the delta method

$^*p < 0.10$; $^{**}p < 0.05$; $^{***}p < 0.01$

Implications of our findings and an agenda for future research

In this paper, we explored characteristics of CRADA activity at NIST using what is arguably the most complete data set of CRADA activity for any Federal laboratory. Although our analysis is based on the most complete data set available on Federal laboratory CRADAs, we were unable to show even descriptively that the samples considered are representative of the population of all NIST CRADAs over the period 1978–2014.

Our findings, subject to the above caveat, are that CRADA activity at NIST statistically increased shortly after the enactment of the Federal Technology Transfer Act of 1986. While one would expect a response after 1986 because the Act authorized CRADAs, our findings suggest that the response was almost immediate rather than delayed. Over three-fourths of NIST's 1891 CRADAs (1978–2014) are with private-sector establishments; an additional 21% are with colleges and universities; the remainder are with other government agencies. Of those 1427 NIST CRADAs that are with private-sector enterprises, over one-half of the CRADAs are in the manufacturing sector.

[25] We emphasize *even* smaller firms. As stated in 15 USC 3710a(c)(4)(A), CRADA preference to small firms is required: "The laboratory director in deciding what cooperative research and development agreements to enter into shall—(A) give special consideration to small business firms, and consortia involving small business firms; …".

We also observed that 910 private sector firms accounted for the NIST CRADAs with private-sector firms, and larger establishments, measured in terms of employment, were more involved in the CRADA activity. However, the employment effect on the propensity to CRADA is very small.

While these descriptive findings offer greater insight into NIST CRADA activity than was previously known, generalizations from these NIST findings to CRADA activities in other Federal laboratories should be made cautiously. Federal laboratories have different missions, and as Link et al. (2011) showed, technology transfer activities are not emphasized to the same degree over the tenure of different laboratory directors. As well, based on our previous discussion about cross-agency laboratory differences in CRADA activity, one should not assume that the CRADA activity at NIST is representative of that at other Federal laboratories.

Our exploratory analysis of these NIST data raises a number of issues that could not be addressed herein but should be addressed for a greater understanding of the role of CRADAs at Federal laboratories. For example, researchers and policy analysts will be better able to assess the net economic benefits from CRADA activity if information is known about private-sector incentives to engage in CRADAs and more precisely if that activity complements or substitutes for in-house R&D. An analysis of incentives might also explain why some firms have over time continued to be involved in CRADA activity with NIST while the majority of firms have done so only once. More broadly, an understanding of such incentives might contribute to a direction for scholars to theorize about the economics of Federal laboratory-with-firm collaborations.[26]

Also relevant to an assessment of net economic benefits would be insight about how CRADA participation affects or leverages other R&D activity both within the Federal laboratory and within the partnering firm. Case studies may be the appropriate research vehicle to use to conduct an assessment of CRADAs. While we treated CRADAs as comparable technology transfer mechanisms, they certainly are not homogeneous in nature. The nature of a CRADA is dependent on both the scope of the research project and the technology skills of all involved researchers (Bodde 1993; Carr 1992a, b).[27]

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References

[26] Adams and Link (2017) and Bray and Link (2017) have explored public policy initiated firm-with-firm collaborations, although neither set of authors speculated how their theoretical and empirical analysis might translate to the public sector being an active collaborator in research.
[27] We thank an anonymous referee for suggesting that we emphasize the heterogeneous nature of Federal laboratory CRADAs.

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