Rensselaer

Working Papers in Economics

Department of Economics, Rensselaer Polytechnic Institute, 110 8th Street, Troy, NY, 12180-3590, USA. Tel: +1-518-276-6387; Fax: +1-518-276-2235; URL: http://www.rpi.edu/dept/economics/; E-Mail: keenak@rpi.edu

The Influence of Federal Laboratory R&D on Industrial Research

James D. Adams
Rensselaer Polytechnic Institute and NBER

Eric P. Chiang
New Mexico State University

Jeffrey L. Jensen
New York University

Number 0301

October 2003

The Influence of Federal Laboratory R&D On Industrial Research*

By

James D. Adams
Rensselaer Polytechnic Institute and NBER

Eric P. Chiang
New Mexico State University

Jeffrey L. Jensen
New York University

JEL Codes: O31, O33, O38 and C25

Address of corresponding author: James D. Adams, Department of Economics, Rensselaer Polytechnic Institute, 3406 Sage Laboratory, 110 8th Street, Troy, NY 12180-3590. Telephone: 1-518-276-2523, fax: 1-518-276-2235, e-mail: adamsj@rpi.edu

* This research was supported by NSF grant SBR-9502968 and carried out while Adams was at University of Florida and Chiang at New Mexico State University. We thank the editor (Robert Pindyck) and a referee, as well as Chunrong Ai, Gary Becker, Maryann Feldman, Adam Jaffe, David Mowery, Ariel Pakes, Sam Peltzman and Geert Ridder for comments. This paper benefited from presentations at Central Florida, Chicago, Florida, Johns Hopkins, Minnesota, and Oslo, as well as NBER. Eleanora Voelkel, Meg Fernando, and Richard Anderson administered the ***Survey of Industrial Laboratory Technologies 1996*** and Katara Starkey administered the ***Survey of Government Laboratory R&D 1998*** that yielded most of the data used in this paper. Within the federal government we thank Karen Azzaro, Mark Boroush, Margaret Brautigam, Richard Burrow, Carol Carlson, Shelly Ford, Ronald Meeks, Robert Rohde, and Sallie Sherertz for information relating to federal laboratories. Of course, any remaining errors are our responsibility.

Abstract

This paper studies the influence of R&D in the federal laboratory system, the world's largest, on firm research. Our results are based on a sample of 220 industrial research laboratories that work with a variety of federal laboratories and agencies and are owned by 115 firms in the chemicals, machinery, electrical equipment, and motor vehicles industries. Using an indicator of their importance to R&D managers, we find that Cooperative Research and Development Agreements or CRADAs dominate other channels of technology transfer from federal laboratories to firms. With a CRADA industry laboratories patent more, spend more on company-financed R&D, and devote more resources to their federal counterparts. Without this influence patenting stays about the same, and only federally funded R&D increases, mostly because of government support.

The Stevenson-Wydler Act and amendments during the 1980s introduced CRADAs, which legally bind federal laboratories and firms together in joint research. In theory the agreements could capitalize on complementarities between public and private research. Our results support this perspective and suggest that CRADAs may be more beneficial to firms than other interactions with federal laboratories, precisely because of the mutual effort that they demand from both parties.

I. Introduction

Since World War II the United States has constructed the world's largest system of government laboratories. In 1995 laboratory research amounted to 26 billion dollars, or 14% of U.S. Research and Development (R&D), a sum greater than all of university R&D and the R&D of many countries. Laboratory R&D includes defense, energy, pollution abatement, mathematics, computer science, astronomy, physics, molecular biology and genetics; the treatment of disease, improvement of the system of measures, and much else besides. Even this understates the influence of the laboratories, given their support of research in universities and firms[1].

In this paper we examine the channels by which federal laboratory R&D could affect research efforts of industrial firms. We examine many different channels, including contractor relationships, use of federal laboratory facilities, patent licensing, cooperative research agreements, movements of scientists and engineers, and several others. But of all these possibilities it is cooperative agreements or CRADAs that are the most telling for firm R&D and patents.

The literature on federal laboratory R&D is not extensive. Most of it concentrates on recent commercialization efforts associated with the National Laboratories run by the Department of Energy. Markusen and Oden (1996) conduct case studies of spin-offs from Los Alamos and Sandia Laboratories in New Mexico. They find that spin-offs are less than firms or universities of similar size. The shortfall is attributed to personnel policies, absence of incentives, and geographic isolation. Still, Markusen and Oden find that the laboratories have advantages as business incubators, which include their unique technologies, the training of their scientists and engineers, and the skill of their machinists and other workers.

Cohen and Noll (1996) discuss the future of the National Laboratories after the Cold War. They argue that cuts in defense research must lead to cuts in civilian research in the laboratories, owing to complementarities between the two kinds of research. Cohen and Noll also suggest that CRADAs cannot solve the problem of declining budgets because of inherent political conflicts over the distribution of laboratory support that accompany CRADAs, despite the value of laboratory expertise for the success of the agreements.

---

[1] For more on the size of the federal laboratories, see National Science Board (1998). Table 4-3, p. A-121 includes statistics on R&D in federal laboratories and other sectors. Table 4-7, p. A-125 includes statistics on basic research performed in federal laboratories and other sectors. Basic research, defined as research designed to gain understanding without specific applications, accounts for an important share of federal laboratory research. In 1995 basic research contributed 67% of university R&D, 23% of federal laboratory R&D, and 4% of industrial R&D.

Ham and Mowery (1998) describe five case studies of CRADAs signed by the Lawrence Livermore National Laboratory. They advise that to be successful CRADAs should include: (a) incentives that ensure commitment; (b) awareness by laboratory researchers of the needs of firms; (c) laboratory flexibility that reduces missteps in project execution; and (d) selection of CRADAs that are consistent with capabilities of the laboratory. And while some CRADAs were unsuccessful, most of the firms felt that the laboratory brought useful competencies to their projects.

Jaffe and Lerner (2001) analyze patents by Department of Energy Laboratories, citations to the patents, and the formation of CRADAs. Their findings include that laboratory patents have increased over time and have reached parity per dollar of R&D with those of universities; that citations per laboratory patent have stayed about the same, suggesting that patent quality has not fallen in spite of the increase in patents; and that successful patenting requires that a laboratory remain focused on its area of competence, preferably in applied research. Similar to patents, CRADAs are likely to be formed when the laboratories emphasize applied research, suggesting that applied laboratories possess technologies that are close to commercialization.

The various studies agree that federal laboratories could in some circumstances contribute to industrial projects. But all of the studies find that weak incentives, geographic isolation and political quarrels have interfered with these contributions. Nevertheless, Jaffe and Lerner (2001) find that dissemination of laboratory technologies has risen and suggest that changes in technology transfer policy may have contributed to this increase.

With this justly skeptical literature as background, we approach the subject of federal laboratory impacts with caution. Our goal is simply to examine the influence of federal laboratory R&D on industrial laboratory patents and R&D. In support of this goal, as noted, our data provide alternative channels by which federal laboratories affect industrial research. Since industrial laboratories are in the forefront of interactions between firms and federal laboratories, our evidence relates to early stages of this contact, before any effects on product markets have occurred (Klette, Moen, and Griliches, 2000). Given that new technology transfer policies have been in place for a decade or so, R&D laboratories are likely places to look for their effects.

As is nearly always the case in empirical research, the data used in this paper have their limitations. Since the data are at the level of R&D laboratories within firms, this implies that firm level information matches very imperfectly with our data on industrial laboratories. Clearly it is desirable to have continuous indicators of contractor relationships, cooperative research agreements, and patents licensed that would complement our mostly

dichotomous indicators of interactions with federal laboratories. But these data are not publicly available[2]. For these reasons we rely on our survey evidence, turning to external data as circumstances permit.

From one perspective the concerns of this paper relate to the appropriate limits of organizations, including that assignment of intellectual property that is most likely to promote innovation. For in licensing patents from federal R&D or in undertaking cooperative agreements where commercial rights to any resulting innovations are given to firms, the government sets a limit to its own authority, assigns intellectual property away from itself, and to that extent privatizes R&D. From another perspective, as we discuss below, the results of this paper suggest that recent efforts may have increased joint research between the federal laboratories and industry and complemented other efforts to commercialize inventions from publicly funded research.

Results from the investigation are the following. First, the influence of the federal laboratories on industrial patenting and R&D depends on the channel of interaction. In head-to-head comparisons of CRADA indicators with alternative channels of federal laboratory effects, we find that CRADAs are the principal means by which federal laboratories influence patenting and company-financed R&D of industrial laboratories. Since CRADAs are agreements that require cost sharing, a close connection to capabilities of the laboratories, and ongoing commitment to be successful (Ham and Mowery, 1998), this suggests that intensive interaction is needed for government laboratories to have an effect. Second, government contractor interactions have little or no effect on industrial patents and company-financed R&D. In contrast CRADAs increase patents, usually with significance, and increase company-financed as well as publicly funded R&D.

The rest of the paper consists of seven sections. Section II describes trends in technology transfer by the federal government since 1980. Section III reviews the literature on property rights economics and models the CRADA arrangement in light of this literature. Section IV describes the data used in this paper. Section V considers the effects of federal laboratories on industrial patents, while section VI presents estimates of a two-equation model of the effect of CRADAs on patents that takes determinants of CRADAs into account. Section VII explores the federal laboratory impact on R&D effort, while section VIII is a summary and conclusion.

[2] Our requests for firm and laboratory level data on CRADAs were repeatedly declined by various agencies. The industrial laboratories in our sample deal with federal laboratories in the Departments of Agriculture, Commerce, Defense, and Energy, as well as the National Institutes of Health, the National Aeronautics and Space Administration, and the Bureau of Mines (now closed). This makes the data collection problem that much more difficult.

II. Federal Technology Transfer Policy Since 1980

The history of the federal laboratories falls into two periods. From 1940 to 1980 the laboratories engaged in internal research and supported research in firms and universities, but were not formally required to commercialize technology[3]. Starting with 1980 commercialization became paramount. Three developments seem to have contributed to this change in policy. First, the end of the Cold War suggested that downsizing of the laboratories was near. Technology transfer offered a "peace dividend" but also the chance to protect laboratory budgets (Cohen and Noll, 1996). Second, productivity growth declined over a twenty-year period beginning in the early 1970s, and the decline appeared to be permanent (Krugman, 1994). Policy makers viewed technology transfer from federal laboratories and universities as a means of restoring growth. Third, the privatization movement (Shleifer, 1998) advocated the sharing of federal technologies with firms in order to make the most out of publicly funded research.

Thus legislation since 1980 has promoted technology transfer between federal laboratories and industry. The Stevenson-Wydler Technology Innovation Act of 1980 made technology transfer a mission of all federal laboratories. The Bayh-Dole Act of 1980 gave title to inventions resulting from federal funding to performers of the R&D. From the special standpoint of the federal laboratory system, Bayh-Dole transferred intellectual property to contractors operating Federally Funded Research and Development Centers. Stevenson-Wydler and Bayh-Dole are complementary pieces of legislation whose goal is to promote commercialization of federally funded R&D. Stevenson-Wydler grants title to patents that result from collaboration with the federal government but involve no direct support from government. Bayh-Dole transfers title to parties who did receive support and whose inventions derived from that support, and enables the licensing of patents that are government-owned[4].

Additional legislation clarified the treatment of intellectual property derived from collaborative agreements[5]. The Federal Technology Transfer Act of 1986 gave incentives to Government Owned and Government Operated laboratories (GOGOs) to commercialize their inventions. The act established a budgetary

[3] Mowery and Rosenberg (1998) document federal programs during 1940-1980 that generated large benefits to the U.S. economy in computers, aircraft, instruments, and electronics, some of them involving the federal laboratories.
[4] For a good discussion of the Bayh-Dole and Stevenson-Wydler Acts, see Schacht (2000).
[5] The National Aeronautics and Space Administration (NASA) was the first federal agency to implement joint research agreements. The Space Act of 1958 allowed NASA to assign intellectual property to collaborating firms and these agreements are known as Space Act Agreements, or SAAs. See NASA (2001) for details.

function for Cooperative Research and Development Agreements (CRADAs), annual reviews of CRADAs by the agencies, and set-asides for the agreements. The National Competitiveness Technology Transfer Act of 1989 extended similar rules to Government Owned and Contractor Operated laboratories (GOCOs). Together the two kinds of laboratories account for most of the R&D conducted in the government.

Other legislation relaxed the application of antitrust to jointly conducted R&D. The National Cooperative R&D Act of 1984 sheltered R&D joint ventures from antitrust action. The National Cooperative Research and Production Act of 1993 extended this protection to joint production of new products arising from R&D joint ventures. Both laws could contribute to technology transfer from federal laboratories to industry. With antitrust protection alliances of firms are allowed to share the benefits from working with federal laboratories. Still, changes in the treatment of cooperative R&D have not fully addressed the problem of creating winners and losers through federal technology transfer (Cohen and Noll, 1996).

It is important to see that there are many channels of technology transfer from the federal laboratories. Formal channels include issuance of patents; exclusive and non-exclusive patent licenses; and CRADAs. Less formally, technology transfer can occur through spin-offs and movements of laboratory scientists to industry and through meetings between laboratory and industrial researchers. The flat profile of laboratory funding and the growth of industrial research since 1987 (U.S. Department of Commerce, 2000) have contributed to outplacement of laboratory scientists. And besides, the Federal Technology Transfer and National Competitiveness Acts have encouraged the laboratories to seek industrial partners. Although evidence on mobility from federal laboratories to firms is scarce, it is likely to have increased in recent years. A study by Feldman (2001) traces the movement of laboratory employees into new firms in the U.S. Capitol region, which has increased partly as a result of policy decisions, including the decline of federal funding in natural science and engineering since the early 1990s (National Research Council, 2001).

The nature of technology transfer varies considerably, including by agency. For example, patent licenses can be exclusive or non-exclusive. The National Institutes of Health (NIH) favor non-exclusive licenses for biological molecules discovered with public funds. NIH also grants non-exclusive licenses under its Materials Transfer Agreements (NIH, 2001). Other agencies such as the Department of Energy (DOE) are more inclined to grant exclusive licenses in order to encourage commercialization.

CRADAs also vary widely. Besides involving one or many firms, contributions by federal laboratories and firms depend on the facts of each case. While CRADAs rule out direct grants (Schacht, 2000), in-kind federal support ranges from half of a project's funding to "funds-in" CRADAs, where firms provide all the funding.

III. Technology Transfer Policy and Property Rights Economics

A. Review of the Property Rights Literature

In this section we review the Property Rights Economics (PRE) literature and draw inferences for recent technology transfer policy, especially CRADAs. Grossman and Hart (1986) construct a theory of the costs and benefits of integration. In their theory integration consists of common ownership of physical assets. The key assumption in their work is that contractual relationships cannot be specified in advance, either because of a large number of contingencies or because investments cannot be verified. Investment decisions are central to the model and lead production decisions, and neither they nor the benefits that follow are contractible. The decision whether or not to integrate, and the decision as to which party should own the assets, depend on which particular arrangement supplies investment incentives that are closest to first-best[6]. They show that non-integration is closest to first-best if investments by both parties are important and if benefits of each party and thus incentives are independent of production decisions by the other. Control by one of the parties is best if that party's investment is the more important and if benefits of the other party are independent of its production decisions.

Aghion and Tirole (1994) extend PRE to the question of whether a customer or a research unit should own an innovation. The allocation of the property right is determined by two factors. First, the property right should be awarded to the party whose value of marginal product is the larger. The logic is that of Grossman and Hart: ownership incentives are scarce and should go to the party whose investment is more important to realizing the benefits from an innovation. Second, the allocation of the property right is always efficient when the research unit has the bargaining power, because the research unit can sell the innovation to the customer. However, allocation of the property right to the customer can be inefficient if the research unit is cash-constrained. In that event the

[6] None of the ownership arrangements are optimal. This is because the first order condition for investment places a weight of _ on the first best marginal benefit and _ on the non-cooperative default marginal benefit (assuming equal sharing of benefits). Thus the allocation of property rights is important because it establishes default payoffs to investment and bargaining power. An allocation that assigns ownership to the party whose marginal product is larger generates first order conditions closer to first best for that party but moves away from first best for the other. Thus incentives are subject to a tradeoff. See Holmstrom and Roberts (1998) for a review and critique.

research unit cannot buy the innovation from the customer, even if that increases its social value.

Hart, Shleifer and Vishny (1997) apply PRE to the problem of whether government should undertake or contract out an activity. One restriction that they impose, which is not perfectly general, is that government employees and contractors are substitutes and not complements. Contractors can allocate effort to product innovation or to cost saving, but cost saving may detract from product quality. Private contractors have more powerful incentives to bring about innovations than government employees because private ownership gives more benefits to the contractor. But contractors may ignore erosion of product quality unless competed against or sanctioned by the loss of contracts. Public ownership dominates contracting when product quality undergoes severe deterioration, though competition and repeat contracting limit the empirical relevance of this issue (Shleifer, 1998).

Now consider the relevance of PRE to technology transfer. First, the assignment of patents from federally funded inventions under Bayh-Dole has increased payoffs to firms, in part through university licensing (Jensen and Thursby, 2001). But firms are the entities most able to commercialize. Thus Bayh-Dole illustrates the appropriate assignment of ownership and incentives to one party, a firm. The other party, the government, does not change its research when property is reassigned (Grossman and Hart, 1986). Second, the Stevenson-Wydler Act and its amendments share intellectual property from public-private collaborations. Firms and federal laboratories provide complementary inputs under CRADAs (Mowery and Ham, 1998). In this case PRE suggests sharing of incentives since both parties' investments are important (Grossman and Hart, 1986; Aghion and Tirole, 1994). Consistent with this view, firms gain from commercialization while the government gains from use of innovations free of royalties.

B. Property Rights Economics Interpretation of CRADAs

Since CRADAs figure prominently in our empirical results we provide an analysis of them in the spirit of PRE. This analysis gives CRADAs the benefit of the doubt and assigns them a productive function. An alternative view is one of political exchange, in which winning a CRADA secures future procurement contracts. Thus patents and private R&D that are attributed to CRADAs could reflect procurement, and conversely some procurement could be due to CRADAs. However, we find rather weak evidence for these hypotheses below.

Let E and e stand for R&D effort of a federal laboratory and firm that are devoted to a particular innovation, and assume that neither R&D is contractible. Since both parties are risk-neutral the laboratory cares only about the expected value of the innovation V_G in the public sector, indicated by subscript G, and the firm cares only about the expected value V_P in the private sector, indicated by subscript P. We also assume that if the

laboratory and firm do not cooperate, then each party can make limited progress in its own sector. Thus the laboratory can generate a value of B_G (E) and the firm can create a value of B_P (e). CRADAs improve on this status quo by legally permitting the parties to conduct joint research. We assume that joint research generates incremental values I_j (E, e), j=G, P. It follows that the value of the innovation given cooperation is

$$V_G = B_G(E) + I_G(E,e)$$
$$V_P = B_P(e) + I_P(E,e) \quad (1)$$

The value functions have the following properties. The base values B_j are concave: $B'j > 0$, $B''_j < 0$, j=G, P. In addition the incremental values $I_j(E,e)$ are increasing in E and e, so that $I_{j1} > 0$, $I_{j2} > 0$, where subscripts 1 and 2 indicate partial derivatives with respect to E and e. The incremental value functions are also concave, so $I_{j11} < 0$, $I_{j22} < 0$, and $I_{j11}I_{j22} - I_{j12}^2 > 0$. And since E and e are complements it follows that $I_{j12} > 0$. We strengthen the role of complementarity between public and private research somewhat further, by requiring that positive incremental value requires positive E and e: $I_j(0,e) = I_j(E,0) = I_j(0,0) = 0$.

The base values B_G and B_P are status quo bargaining points, while $I_G + I_P$ is the social surplus from joint research. The net social value of the innovation with joint research is $V_G + V_P - E - e = B_G + B_P + I_G + I_P - E - e$. In the classic renegotiation phase the two parties split the social surplus 50:50 and maximize their private net gains on this basis. The gain for the federal laboratory is then $B_G + \frac{1}{2}(I_G + I_P) - E$, while the gain for the firm is $B_P + \frac{1}{2}(I_G + I_P) - e$. First order conditions for laboratory and firm are thus

$$B'_G + \tfrac{1}{2}(I_{G1} + I_{P1}) = 1$$
$$B'_P + \tfrac{1}{2}(I_{G2} + I_{P2}) = 1 \quad (2)$$

Equation (2) yields the solution $E = \hat{E}$ and $e = \hat{e}$. However, it may be possible to improve on (2) using contracts that more closely resemble CRADAs. Assume that $I_{G1} > I_{P1}$ and $I_{G2} < I_{P2}$ for any positive E and e, so that government laboratories have an absolute as well as comparative advantage in creating public sector value ($I_{G1} > I_{P1}$) while firms enjoy an advantage in the private sector ($I_{G2} < I_{P2}$). In effect, each party knows its own business best. Given these assumptions about the laboratory and firm we can show that both parties will receive larger benefits and do more R&D if 100 percent of the public sector value goes to the federal laboratory and 100 percent of the private sector value goes to the firm, like the split property rights analysis of Aghion and Tirole

(1994). According to this division of the rewards, net gains for laboratory and firm are $B_G + I_G - E$ and $B_P + I_P - e$. Then the first order conditions for R&D are

$$B'_G + I_{G1} = 1 \qquad (3)$$
$$B'_P + I_{P2} = 1$$

Equation (3) yields the solution $E = \tilde{E}$ and $e = \tilde{e}$. It is easy to show that if knowing one's own business is best, then R&D increases under (3) compared with (2), so that $\tilde{E} > \hat{E}$ and $\tilde{e} > \hat{e}$. Since in that event $I_{G1} > I_{P1}$, it follows that $I_{G1} > \frac{1}{2}(I_{G1} + I_{P1})$. Likewise $I_{G2} < I_{P2}$ for all positive E and e implies $I_{P2} > \frac{1}{2}(I_{G2} + I_{P2})$. Thus at the same $\hat{E}$ and $\hat{e}$ that satisfy (2), $B'_G + I_{G1} > 1$ and $B'_P + I_{P2} > 1$. E must then increase. First, holding e constant, B'_G and I_{G1} decrease in E, so that E must increase to restore the first equation in (3). Second, an increase in e increases I_{G1}, since $I_{j12} > 0$, and implies a further increase in E. The analysis of e is similar.

We can add to the above interpretation an explanation of "funds-in" CRADAs, where companies pay all the cost of the government's research as well as their own[7]. Assume that private sector benefits to firms from joint research greatly exceed public sector benefits to federal laboratories. In this setting firms can increase R&D by federal laboratories by paying the marginal cost of the government's research. By this means the firm secures an increase in E as well as the private benefit I_P, moving both to a level that is closer to first-best.

IV. Description of the Data

Having reviewed the literatures of federal technology transfer and Property Rights Economics, we turn now to the empirical analysis. Most of the data used in this paper derive from two surveys. A 1996-1997 survey of industrial laboratories collected data on R&D, patents, and the nature of laboratory contacts with other R&D performers. These include two types of interactions with federal laboratories. First, industrial laboratories were asked to rank an array of interactions with federal laboratories on a scale of 1 to 5 in order of increasing importance. Second and conditional on some interaction, the industrial laboratories were asked to cite particular federal laboratories that were influential for their research.

[7] The well-known Extreme Ultraviolet Lithography CRADA is an example of a funds-in CRADA in which partner firms—Intel, Advanced Micro Devices, Motorola, and IBM—paid all the costs of the research. The resulting invention successfully uses hard ultraviolet light to increase the density of transistors on computer chips (see "Extreme Measures," **The Economist**, June 23, 2001).

A 1998 survey collected data on intramural or on-site R&D carried out in federally funded laboratories—the same that are cited by the industrial laboratories in the 1996 survey[8]. The follow-up survey was necessary because there is no comprehensive, published source of information on the R&D of federal laboratories.

A. Survey of Industrial Laboratory Technologies 1996

The industrial laboratory survey collected R&D budgets, company and publicly financed shares of R&D and detailed information on the channels and sources of federal laboratory spillovers relevant to the laboratories. First we randomly selected 200 companies from a population of 500 firms in the chemicals, machinery, electrical equipment, and motor vehicle industries. Firms in the target population had to be included in Standard and Poor 's 1995 Compustat database, had to report R&D and sales, and had to name-match assignees in the U.S. Patent and Trademark Office (USPTO) database. Thus, the population consisted of publicly traded, high technology firms in the four industries whose size, R&D intensity, and patents were known. Motor vehicle firms were deliberately over-sampled compared with other industries because of response-rate concerns. Partly as a result of this over-sampling our combined sample contains firms that are larger than firms in the population. A response bias analysis, however, finds no significant difference between sample means and population means for firm sales, R&D, or R&D intensity[9].

The 200 firms owned about 600 laboratories whose address information was taken from the **Directory of American Research and Technology** (R.R. Bowker, 1997)[10]. Responses to the survey include 208 laboratory observations from 115 responding firms. The 208 observations actually account for 220 laboratories because three of the firms responded at the corporate level. Thus, the implied response rate was 37% (220/600). Of the 116 firms, 29 were publicly traded for less than 16 years in 1996, so that young companies as well as old form an important part of the sample. Respondents were R&D managers with considerable knowledge of their firms. They were in industrial research for an average of 17 years and with their firms for an average of 15 years.

One could ask whether the laboratories in our sample accurately represent R&D in their companies. It is quite hard to answer this question because information on the laboratories forms an element of corporate strategy

[8] On-site federal laboratory R&D is the preferred measure, since the laboratories spend the rest of their R&D on contractors, opening up the possibility of double counting in R&D budgets of contractors and federal labs.
[9] Survey firms reported an average of $211.1 million of R&D and $4523.2 million in sales in Compustat. Population firms reported an average of $114.6 million in R&D and $2274.6 million in sales. Two sample t-tests of the difference in means of R&D and sales (assuming unequal variances) were 1.43 and 1.48 respectively and thus were insignificant. Likewise R&D intensities were similar, 0.047 for the sample and 0.050 for the population.

and as a result is proprietary. In addition there are issues of comparability between R&D in Compustat and the survey. Compustat R&D is influenced by R&D tax credits and may include non-R&D portions of the R&D budget, while R&D in the survey is careful to exclude all overhead and non-R&D charges[11]. For this reason we simply say that the data represent a sample of laboratories taken from the sample of firms. This statement reflects the reality of research groups operating within firms and the two-stage nature of data collection in this area.

Table 1 shows the distribution of firms and laboratories by industry. The distribution is uniform except for smaller numbers in motor vehicles that correspond to the greater degree of concentration in this industry. Response rates are roughly equal across industries. Notice that numbers of laboratories in table1 are upper bounds on the observations for each year's worth of data in the regression tables, since missing values are ignored.

Table 2 displays size characteristics of the R&D laboratories classified by their connection to federal laboratories. Since the data were cover 1991 and 1996 we are averaging over the two years as well as laboratories in these calculations. The top panel shows R&D inputs: the number of scientists and engineers, number of Ph.D. or MD researchers and laboratory R&D budget in millions of 1987 dollars[12]. The bottom panel shows R&D outputs measured by the number of patents issued. Table 2 reports two measures of patents. The first is patents granted in 1991 and 1996 as reported in the survey. Not all laboratories report their patents. Thus the second measure of patents replaces missing patents with an estimate for the firm, laboratory location, and year. Imputed patents derive from the U.S. Patent and Trademark Office and were downloaded from the **U.S. Patents Database** (Community of Science, 1999). The method for obtaining the estimate is this. We match two-digit zip codes to the addresses of all inventors for a company using the zip code database of the U.S. postal service. Next we assign all patents of the parent firm to the location if the inventor's zip code matches the zip code of the laboratory. Finally we assign patents to years 1991 and 1996 according to their issue dates[13]. We call this result, augmented patents.

The imputation method is the best we could devise and yet it contains errors. Inventors may live in a different zip code and state than the laboratory and their patents are ignored by our method. Patents can include

---

[10] The survey instrument was refined in three stages. A retired R&D manager read and critiqued the initial draft. Then a beta version was tested on 10 nearby laboratories. Using these comments a final draft was produced. The survey team then mailed the survey to all laboratories that granted permission to send the instrument.

[11] In two case studies that we have conducted we find that, based on information provided by R&D executives, the R&D budget of the central research laboratory was approximately one-tenth of Compustat R&D.

[12] R&D in the laboratory survey tries to follow NSF definitions. However, R&D in the survey data is net of overhead expenses and non-R&D charges, and for this reason may be a leaner concept than in some other data.

[13] We thank Meg Fernando for downloading the patent data from the Community of Science web site and for translating the text fields into SAS™ for further analysis.

multiple inventors in the same firm who cluster in different zip codes, and worse, in the same zip code. Both cases over-count the firm's patents. We handle the first problem by multiplying patents by the fraction of the top four inventors on the patent that are in the same two-digit zip code as the laboratory. We deal with the second problem, of clustering of the firm's laboratories in the same zip code, by apportioning the total number of patents of the different laboratories according to each laboratory's share in total scientists and engineers for the firm and location.

Table 2 shows that larger industrial laboratories are more likely to be associated with federal laboratories. Affiliated laboratories employ three times as many scientists, nearly seven times as many Ph.D. or MD researchers, and do more than twice as much on R&D as other laboratories. Patents issued by laboratories that are associated with government are also more than twice as large. Given the role of size in the selection process for government affiliation we are careful to control for laboratory size in the regressions reported below.

The survey measures ten interactions between industrial and federal laboratories. Table 3 describes these and reports the percent of industrial laboratories rating each interaction as important. Not all imply technology transfer. Government contractors manufacture products to specification but need not be engaged in product development. Likewise SBIR awards finance small projects in universities and startups but do not provide the projects. Use of test facilities, outflows of scientists to government laboratories, and outflows of ideas to government laboratories do not necessarily imply technology transfer from the government.

Five of the interactions do suggest technology transfer. These are licensing of government patents, involvement in CRADAs, inflows of scientists from government laboratories, inflows of ideas from government laboratories, and use of industry-government technology transfer centers. We mark these accordingly in table 3 and examine their distribution in table 4. Fifty-eight percent of laboratories rank none of the technology transfer indicators as important. The distribution of the number of indicators is essentially flat among the remaining 42 percent. This suggests that multiple channels of communication contribute to technology transfer.

For the empirical work we code each of the interactions as dummy variables equal to 1 if the private laboratories rated an interaction as important, and 0 otherwise. For some purposes we sum across dummy variables coding for technology transfer, or we recode the individual indicators to show technology transfer of a certain kind. In the case of CRADA, which turns out to be an important variable, we do not have the number and value of the agreements in each year because the data are not publicly available. Instead we have a dummy variable that measures the importance of CRADAs to R&D managers. This scale-free, time-invariant measure prevents us from

including fixed effects in our econometrics. However, it has the advantage that it pertains to individual laboratories within firms and indicates whether CRADA and other interactions are important in the opinion of R&D managers.

B. Survey of Government Laboratory R&D 1998

Contingent on some interaction, the industrial laboratories in the 1996 survey were asked to write down particular federal laboratories that were significant for their research. The result was a name and address list of federal laboratories[14]. Using this information we identified laboratories by federal agency using U.S. General Accounting Office (1996). Large numbers were in DOE and Department of Defense (DOD) with lesser numbers in NASA and the Departments of Commerce, Health and Human Services (HHS), and others. In six cases respondents cited non-profit laboratories that were funded by government, which we call federally funded R&D laboratories.

Given this list we sought to construct spillovers of R&D from published data on the federal laboratories in order to test a simple model of public-private interactions. The idea is that larger pools should represent a larger source of knowledge than smaller pools and automatically transmit more knowledge to the industrial laboratories[15]. The chief alternative to this view is that knowledge spills over when a firm devotes resources to making the knowledge spill over (Cohen and Levinthal, 1989). This second argument suggests that the firm is interested in the small part of federal research that is opened up by research collaboration.

We need at least three pieces of evidence to test the hypothesis that larger laboratories provide larger spillovers. These are (1) a history of federal laboratory R&D that begins at least a decade before the survey data, in order to compute a partial R&D stock. In addition we require (2) data on on-site or intramural R&D, which is distinct from contracts and grants and avoids double counting in the budgets of private and federal laboratories. Finally (3), we would like data on research divisions in a laboratory to capture diversity of R&D within federal laboratories and serve as a real deflator of that R&D[16]. However, we were unable to construct the spillovers. Only DOD consistently has this information (Defense Technical Information Center, various years).

We lacked data on spillovers for most government laboratories except for DOD and a few exceptions in National Science Foundation (various years). With the sole purpose of constructing spillovers of government

[14] Our respondents cite 69 federal laboratories located in the Department of Energy, Department of Defense, National Aeronautics and Space Administration, Department of Commerce, National Institutes of Health, Department of Agriculture, and the now defunct Bureau of Mines. This is likely to be an undercount though, because some of our laboratories regarded this information as proprietary.

[15] See Cockburn and Henderson (1996), Ham and Mowery (1998), and Adams (2002) for a critique of this view.

laboratory R&D we conducted the **Survey of Government Laboratory R&D 1998** (Adams, 1998). This survey polled chief financial officers (CFOs) of non-DOD federal laboratories and had a response rate of 97%[17].

Inevitably, the data on R&D of federal laboratories contain measurement error. Respondent error by industrial laboratories is probably the most important since citations refer to all of a federal laboratory rather than the "sending" division. In addition agencies aggregate differently and this leads to more errors. Finally, data quality varies by agency and respondent in the federal laboratory survey.

Forty-five percent of private laboratories report some interaction with federal laboratories. Of these nearly all or 42 percent, report that at least one of the technology transfer channels (see table 3) was important for their research. Of the 45 percent having a federal lab connection, two thirds or 31 percent describe particular federal laboratories that were influential for their research. We refer to these as closely affiliated federal laboratories.

Contingent on citation, mean numbers of federal laboratories and their research divisions were 3.5 and 20.5, indicating six divisions per federal laboratory. For each federal laboratory we construct 10-year stocks of R&D in millions of 1987 dollars discounted at 15 percent. The R&D stocks end one year prior to the survey data dated as of 1991 and 1996. From the standpoint of citing R&D laboratories stocks of federal R&D are sums over R&D stocks of cited federal laboratories. The average federal laboratory has a stock of total R&D of about 9 billion dollars. Intramural stocks are about 4 billion[18]. The divisional stocks of total and on-site R&D are respectively 500 and 200 million dollars. These figures indicate the extraordinary size of the federal laboratories.

We adopt the following policy for keeping observations in regressions that include R&D stocks of cited federal laboratories. If a federal laboratory connection was declared and federal laboratories were cited then we keep the observation. If there was no connection, then that observation is also kept. But if a connection was declared and no federal laboratory was cited we drop the observation because the data are censored.

C. Supplemental Data

Besides the survey evidence we introduce R&D and net sales of parent firms from Compustat (Standard and Poor, 1994). The Compustat data give us two variables that play a useful role in the empirical work. The first is

---

[16] This idea first appears in Evenson and Kislev (1973). Adams and Jaffe (1996) and Adams (1999) make use of "real" deflators of R&D consisting of numbers of plants by location or technology.

[17] In some cases we obtained data on federal laboratory R&D from both the 1998 survey and published sources. In all such cases the two sets of figures matched closely.

R&D in the rest of the firm in millions of 1987 dollars. This variable controls for R&D elsewhere in the firm, which could contribute to patents in addition to laboratory R&D. The second is the logarithm of the stock of recent sales of the firm. In constructing this stock we express sales over the previous 12 years in millions of 1987 dollars, depreciate them at a rate of 15 percent, sum the result, and take logarithms. Recent firm sales control for size of the firm. Another size measure from Compustat, stock market value, performs in a similar way to recent sales.

Finally we include the value of R&D and non-R&D procurement contracts by firm and location. The data span the period 1991 to 1996 and include the Departments of Commerce, Defense, Energy, Health and Human Services, and NASA, the five principal agencies with which firms were affiliated[19]. Based on these data we construct the value in millions of 1987 dollars of contracts for the same two-digit zip code and firm as the laboratory, and elsewhere in the firm. The point of constructing these variables is that CRADAs could be a veil for rent seeking if the purpose of the agreements is to generate procurement. Thus, holding procurement constant is useful for verifying the effect of CRADA. However, procurement does not change the CRADA effect.

V. The Influence of Federal Laboratories on Industrial Patents

Tables 5 and 6 include single equation results for patents issued to private R&D laboratories. The estimation method is negative binomial regression, a type of random effects Poisson. Many of the laboratories do not patent and the mean number of patents is close to zero. Poisson regression is one way of handling such count data but it has a drawback because it fails to handle over-dispersion of counts in microdata. Negative binomial regression corrects for the over-dispersion problem[20]. In all the regressions the statistics for over-dispersion are highly significant and support the Negative Binomial over the Poisson.

---

[18] The fraction of total R&D that is conducted on-site ranges from 1 to 99 percent across the cited group of federal laboratories. This indicates the heterogeneity of the laboratories in the degree to which they contract out research, and the importance of obtaining intramural R&D to correctly measure internal laboratory R&D.

[19] The source is the procurement transactions database of the General Services Administration (GSA), which records all procurement expenditures in the federal government. Over the 1991 to 1996 period roughly 60,000 of these transactions apply to companies in the survey data.

[20] Maddala (1983), Ch. 2 is a basic treatment of Poisson regression. Hausman, Hall and Griliches (1984) discuss the extension to the negative binomial. Johnson and Kotz (1969) derive the negative binomial as follows. Assume that the count data are Poisson distributed for a given parameter λ, and further assume that λ is a random variable that follows the Gamma distribution. Then the unconditional distribution of the data follows a negative binomial.

The following passage interprets the parameters in Negative Binomial regression. To ensure non-negativity the computational algorithm writes the logarithm of the Poisson parameter λ_i as a regression function:

(4) $$\log \lambda_i = x_i'\beta$$

This parameter determines the expected number of patents. It follows from (4) that if x_{ij} an element of x_i is specified in logarithmic form, β_j is the elasticity of patents with respect to x_{ij} .

We provide a more elaborate analysis for x_{ij} a dummy variable, since our federal laboratory interactions take this form and are a cornerstone of the analysis. Take the anti-logarithm of (4) to obtain the expected number of patents for the ith observation λ_i . Let $\lambda_i^{\,0}$ and $\lambda_i^{\,1}$ stand for expected patents when x_{ij} equals 0 or 1 respectively.

Then the change in the number of patents due to x_{ij} changing from 0 to 1 is:

(5) $$\Delta\lambda_i \;..\lambda_i^{\,1} - \lambda_i^{\,0} = e^{x_{i.j}\beta_{.j}+\beta_j} - e^{x_{i.j}\beta_{.j}} = \lambda_i^{\,0}\left(e^{\beta_j} - 1\right)$$

The equation uses the notation $x_i'\beta = x_{i.j}\beta_{.j} + x_{ij}\beta_j$ to partition the regression function, as well as x_{ij} =1 to write $\lambda_i^{\,1}$ and x_{ij} =0 to write $\lambda_i^{\,0}$. The expression on the far right follows from the definition of $\lambda_i^{\,0}$. Equation (5) is the expected change in patents for the ith observation due to a dummy variable changing from 0 to 1. But we are really interested in the *mean* effect of a change in the dummy variable, using the sample of observations where the dummy equals zero as a baseline. Let $\bar{\lambda}^0$ stand for mean patents for the x_j =0 sub-sample and let $\tilde{\lambda}^1$ represent the effect on mean patents of a change in x_j from 0 to 1. Using (5) we write the predicted change in patents as

(6) $$\Delta\bar{\lambda}^0 \;..\tilde{\lambda}^1 - \bar{\lambda}^0 = \bar{\lambda}^0\left(e^{\beta_j} - 1\right)$$

The ratio of (6) to the difference in mean patents in samples where the dummy is 1 and 0 respectively ($\bar{\lambda}^1 - \bar{\lambda}^0$) is a comparison function that is useful in gauging the mean effect of the dummy:

(7) $$R_{\Delta\bar{\lambda}^0} \;\ldots\frac{\Delta\bar{\lambda}^0}{\bar{\lambda}^1 - \bar{\lambda}^0}$$

We make frequent use of (6) and (7) in assessing the impact of CRADAs on patents below.

We now turn to table 5. Patents granted are the dependent variable in equations 5.1 to 5.4. Augmented patents are the dependent variable in 5.5 to 5.8. Since these include imputes, we insert a dummy to absorb the effects of imputation. The imputation dummy is positive and significant indicating the larger size of laboratories in

imputed cases but also the tendency for imputed patents to be more inclusive. All equations include dummies for year and industry. Two other dummies describe specialization. We find that laboratories that engage in routine testing patent less, though the effect is not significant. Joint housing with manufacturing is also insignificant. Separately housed laboratories focus on research, making them more prone to patent, but they are also engaged in work that is closer to basic science. This makes them less prone to patent so the net effect is zero.

The rest of the table considers the effect of current laboratory R&D, rest of firm R&D and the interactions with federal laboratories, including the value of procurement contracts[21]. Throughout laboratory R&D is positive and highly significant though its elasticity (about 0.7) is significantly less than 1.0. While the returns to patenting may be diminishing, it is more likely that larger laboratories report their R&D more consistently than smaller laboratories. Equations 5.4 and 5.8 split laboratory R&D budget into company-financed and federally funded components. Only company-financed R&D increases patenting. This may indicate that government contracts dominate federally funded R&D, for which patent rights or technological opportunities are limited.

We include the logarithm of R&D elsewhere in the firm to control for size and the benefits of research conducted in other parts of the company. Its effect on laboratory patents is positive and significant, though its elasticity (0.06) is less than a tenth of the elasticity of laboratory R&D. We have suggested that rest of firm R&D could measure the firm's ability to capture returns to its R&D. Alternatively, rest of firm R&D could reflect joint research within the firm. In regressions not shown we also include recent sales of the firm to capture size. Sales are insignificant while rest of firm R&D remains significant, apparently capturing joint research.

Table 5 contains three indicators of government laboratory interaction. Government Contractor is a dummy equal to 1 (and 0 otherwise) when a private lab indicates that a contractor relationship with the federal laboratories is important. Government Contractor has a negative coefficient in the patent equations, perhaps suggesting that rights to government-sponsored R&D remain with government. CRADA significantly increases patents, consistent with the view that it expedites technology transfer. This effect weakens (see 5.4 and 5.8) when federally funded laboratory budget is included as a separate variable, presumably because federal support is correlated with CRADA.

[21] We used current R&D of the laboratory and current patents because of time constraints on the survey respondents. However, in part because of serial correlation in R&D related to adjustment costs, current R&D is frequently found to be strongly associated with current patents at the firm level. Two notable early studies, those of Scherer (1965) and of Griliches and Pakes (1984), find that current R&D is the predominant contributor to patents, even though the relationship should be lagged. Thus current R&D in our study is a proxy for recent R&D of the lab. Rest of firm R&D is the 13-year stock of R&D of the firm lagged one year, from Compustat.

The remaining indicator, on-site R&D in closely affiliated government laboratories, is never significant. In regressions not shown we add a dummy for the importance of licensing government patents, but this is never significant. CRADA is the only federal laboratory interaction that contributes to industrial patents. This raises anew the question of how to measure its effect.

We use (6) and (7) for this purpose. To do so we require mean patents $\bar{\lambda}_0$ for laboratories where CRADA=0 and $\bar{\lambda}_1$ for the sample where CRADA=1. In the data $\bar{\lambda}_0$ =5.93 and $\bar{\lambda}_1$ =17.80[22]. From table 5 we apply values of β_j =0.4 or 0.5 in (6). The estimated effect of CRADA on the number of patents ($\Delta\bar{\lambda}_0$) using these values for β_j is 2.91 or 3.85 patents. Since CRADA could stand for several cooperative agreements and since agreements in other studies are worth about one million $ (Ham and Mowery, 1998), these figures seem within range. Furthermore, using the relative measure $R_{\Delta\bar{\lambda}^0}$ from (7), we can compute the fraction of the mean difference in patents that is accounted for by CRADA. Substituting $\bar{\lambda}_1$ =17.80 and $\bar{\lambda}_0$ =5.93 and $\Delta\bar{\lambda}_0$ =2.91 or 3.85 into (7) we find that $R_{\Delta\bar{\lambda}^0}$ ranges from 0.25 to 0.32. We conclude that most of the difference in patents between the two samples is due to the laboratories rather than CRADA. This again seems reasonable.

Procurement in the vicinity of the laboratory is at most marginally significant. Procurement in the rest of the firm is negative and significant, perhaps reflecting movement of R&D to the rest of the firm. But procurement has little to do with the effect of CRADA. If we omit the procurement variables the coefficient of CRADA remains about the same. This pattern continues to hold when procurement is broken up into R&D and non-R&D components and when current procurement is replaced by cumulative procurement over the period 1991-1996. Procurement considerations are not driving the CRADA effect observed in our data[23].

Table 6 further explores the effect of CRADA. We set up a competition between CRADA and other technology transfer indicators to see which dominates. The collection of indicators on each line is extracted from regressions specified exactly as in table 5. Technology transfer indicators are on the left. Estimated coefficients are on the right, with t-statistics in parentheses. The table reports eight combinations of technology transfer interactions.

[22] Laboratories for which CRADAs are not important issue 5.93 patents and have R&D budgets of 4.48 million $. Laboratories for which CRADAs are important issue 17.8 patents and have R&D budgets of 23.13 million $.
[23] In addition we estimated Probit equations that included procurement and other variables, and where CRADA was the dependent variable. The procurement variables were insignificant, again suggesting that they are not driving the CRADA effect.

ANY is a dummy variable equal to 1 if any of the technology-transfer indicators in table 3 (licensing of government patents, use of CRADAs, inflows of ideas from government laboratories, inflows of government scientists, and use of industry-government technology transfer centers) are important. Otherwise, ANY equals 0. ANY is insignificant until Government Contractor is introduced on the second line of the table.

ALL is the sum of the five technology transfer indicators and accordingly ranges from 0 to 5. ALL is a more significant contributor to patents than ANY, especially when Government Contractor is introduced. This is because ALL captures intensity of interactions with government laboratories in a way that ANY does not.

The last four lines of table 6 separate CRADA from ANY and ALL. ANY OTHER is a dummy variable that equals 1 if some other technology transfer indicator besides CRADA is important, and 0 otherwise. The fifth line of table 6 separates ANY into ANY OTHER and CRADA. ANY OTHER is negative and insignificant while CRADA remains positive and significant. The sixth line adds Government Contractor to the specification. ANY OTHER is again insignificant while CRADA strengthens, suggesting that omission of Government Contractor causes a downward bias in the CRADA coefficient. Lines seven and eight separate CRADA from ALL. We decompose ALL into ALL OTHER and CRADA. Otherwise the regressions are comparable to lines three and four. Again ALL OTHER is insignificant while CRADA retains its effect.

In these data federal laboratories exert their primary effect on industrial patents through CRADA. But in spite of all the controls CRADA could still reflect fixed effects of the laboratories rather than cooperative agreements, a point that we address in the next section.

VI. Joint Determination of Industrial Patents and CRADAs

So far we find that CRADAs increase patents but we have not explored the possibility that CRADAs are themselves influenced by unobserved quality of the laboratories. And yet industrial laboratories that collaborate with federal laboratories are larger than average (see table 2) and are likely to be more productive than average. One view of the process generating the observations is that CRADA is a dummy variable in a simultaneous equation system[24]. According to this interpretation patents are a function of laboratory R&D budget, CRADA, industry and year dummies and specialization of the laboratory[25]. At the same time CRADAs are a function of laboratory R&D

[24] Heckman (1978) develops the theory of dummy endogenous variables in a simultaneous equation system and applies the theory to anti-discrimination laws. Maddala (1983), Ch. 5 contains a survey of this literature.
[25] An alternative view emphasizes the role of selectivity. According to this view, the error term of the patent equation of (8), which may be interpreted as unobserved research productivity, can be expressed as a function of

budget; industry and year dummies; and other interactions with federal laboratories, including Government Contractor. Both equations are part of a two-equation system that allows for cross-correlation of the errors.

The equation system for this model does not allow for feedback from patents to CRADA and the following discussion shows why. First we model the patent indicator as an Ordered Probit variable where patents fall into increasing intervals. This lets us estimate the correlation between the Ordered Probit indicator for patents and the Probit indicator for the importance of CRADAs using bivariate normal theory. The two-equation system is

$$y_1^* = \beta_2 y_2 + \gamma_1' X_1 + u_1$$
(8)
$$y_2^* = \gamma_2' X_2 + u_2$$

Here y_1^* is the latent indicator of patents, y_2 is the observed 0-1 indicator for the importance of CRADAs to the laboratory and y_2^* is the latent indicator for CRADA interactions. Also X_1 and X_2 are the independent variables and u_1 and u_2 are the error terms. The reason why patents do not feedback to CRADAs, so that $\beta_1 y_1$ (where y_1 is the observable indicator of y^*_1) does not appear in the second equation of (8), is that the probabilities do not sum to unity unless β_1 equals zero[26]. This consistency condition is necessary if the model is to have a proper distribution and leads some writers to call models like (8) recursive models, even though the errors u_1 and u_2 are not independent and the term recursive is usually reserved for the independent case. The principal gain from using (8) is that it lets us estimate the correlation between u_1 and u_2, as in Seemingly Unrelated Regression.

Next, the probability that patents lie in interval j and that CRADAs are important is

---

CRADA. The reason is that the propensity to receive CRADAs and to regard them as important is a function of unobserved patent productivity. See Olley and Pakes (1996) for an exposition of this approach and its application to the telecommunications equipment industry. But in our case, unlike theirs, there is no obvious sample selection: R&D labs do not disappear from the sample as a result of not receiving a CRADA.

[26] The proof, which is available on request, extends Maddala (1983), chapter 5.7. Sum the probabilities for the ordered Probit-Probit model with $\beta_1 \neq 0$ in the second equation of (8) and $\beta_2 \neq 0$ in the first. It is straightforward to show that the sum is not equal to 1, so that the probability distribution is not proper, unless $\beta_1 = 0$. This assumes as is necessary in our case, that $\beta_2 \neq 0$ in order to measure the effect of CRADA. In other settings the probabilities sum to one if $\beta_1 \neq 0$ and $\beta_2 = 0$ in the first equation of (8). But β_1 and β_2 cannot both enter (8).

$$\Pr(y_1 = j, y_2 = 1) = P(c_j > y_1^* > c_{j-1}, y_2^* > 0)$$

$$= P(c_j > y_1^* > c_{j-1}) - P(c_j > y_1^* > c_{j-1}, y_2^* < 0)$$

(9) $$= \left[P(c_j > y_1^*) - P(c_j > y_1^*, y_2^* < 0)\right] - \left[P(c_{j-1} > y_1^*) - P(c_{j-1} > y_1^*, y_2^* < 0)\right]$$

$$= \left[\Phi\left(c_j - \beta_2 - \gamma_1' X_1\right) - F\left(c_j - \beta_2 - \gamma_1' X_1, -\gamma_2' X_2, \rho\right)\right]$$

$$- \left[\Phi\left(c_{j-1} - \beta_2 - \gamma_1' X_1\right) - F\left(c_{j-1} - \beta_2 - \gamma_1' X_1, -\gamma_2' X_2, \rho\right)\right]$$

The equality sign on the first line of (9) states the equivalence between observable and latent variables determined by the "cut points" c_j and c_{j-1}. The equality on the second line shows the conversion between the probability of y_2^* exceeding 0 and its equivalent, 1 minus the probability that y_2^* is less than 0. The equality on the third line expresses the probability that y_1^* lies between two cut points as the corresponding difference in probabilities that y_1^* is less than each cut point. Lines two and three rewrite the probability of jointly observing $y_1 = j$ and $y_2 = 1$ in terms of univariate and bivariate cumulative distribution functions (CDFs). This is necessary because standard software catalogues only CDFs. The fourth and fifth lines impose the assumption of normality on each of the CDFs since $\Phi(\langle)$ is the standard univariate normal CDF and $F(\langle)$ is the standard bivariate normal CDF assuming a correlation coefficient ρ. We assume standard normal distributions, since Probit analysis does not identify variances and co-variances.

Equation (9) specifies the branch of the likelihood function where CRADAs are observed to be important to the laboratory. The probability of observing the other branch, where CRADAs are not important, is

$$\Pr(y_1 = j, y_2 = 0) = P(c_j > y_1^* > c_{j-1}, y_2^* < 0)$$

(10) $$= \left[P(c_j > y_1^*, y_2^* < 0) - P(c_{j-1} > y_1^*, y_2^* < 0)\right]$$

$$= \left[F\left(c_j - \gamma_1' X_1, -\gamma_2' X_2, \rho\right) - F\left(c_{j-1} - \gamma_1' X_1, -\gamma_2' X_2, \rho\right)\right]$$

As in (9) the first line states the equivalence between the observable and latent indicators. The second line again expresses the bracketed probability that y_1^* lies between two cut points as the equivalent difference in probabilities

that y_1^* is less than each cut point and translates the probabilities into computable CDFs. The last line imposes normality on the CDFs, where $F(\langle)$ is the standard bivariate normal CDF, assuming a correlation coefficient of ρ .

The likelihood function is the product of (9) and (10) across observations:

$$(11) \qquad L = \prod_i \prod_j \left[P(c_j > y_{1i}^* > c_{j-1}, y_{2i}^* > 0) \right]^{Z_{ij}} \langle \left[P(c_j > y_{1i}^* > c_{j-1}, y_{2i}^* < 0) \right]^{Z_{ij}} ,$$

where i is the observation and $Z_{ij} = 1$ if y_{1i}^* falls in category j of patents and 0 otherwise.

Table 7 contains the results for the two-equation econometric model consisting of (8)-(11)[27]. Equation 7.1 presents single equation, Ordered Probit estimates of the patent equation in which categorical patents are PATCAT[28]. CRADA is highly significant as before. Equation 7.2 reports single equation Probit estimates of the CRADA equation that include a battery of other interactions with government labs as instruments. These interactions include Government Contractor, inflows of ideas from government labs, inflows of scientists from federal labs, licensing of government patents, test facilities in government laboratories, and industry-government technology transfer centers. The logarithm of R&D conducted elsewhere in the firm is excluded from 7.2 on the grounds that size and quality of the laboratory attract CRADAs, not research elsewhere in the firm[29]. The results of 7.2 suggest that Government Contractor, inflows of ideas, and licensing of government patents are the most important determinants of CRADA.

Equations 7.3 and 7.4 contain the two-equation maximum likelihood estimates of PATCAT and CRADA. The key result is that taking cross-equation correlation into account increases the point estimate of CRADA and also its standard error, but CRADA remains significant. The correlation between the error terms of the PATCAT and CRADA equations is negative but insignificant[30].

We also estimate (8)-(11) using augmented patents, which include imputes for missing patents. The results are similar to those in table 7. In the single equation results for PATCAT the coefficient for CRADA is 0.34 (t=2.4). In the two equation maximum likelihood results, the coefficient of CRADA is 0.41 (t=1.9). The cross-equation correlation is negative, but insignificant.

---

[27] The STATA™ program that computes the estimates is available on request. See Gould and Sribney (1999) for an introduction to maximum likelihood estimation using STATA™.

[28] The 10 categories of PATCAT correspond to 0, 1, 2, 3, and 4 patents, 5-7 patents, 8-10 patents, 11-20 patents, 21-40 patents, and 41+ patents. The intervals are chosen to avoid cells with few observations on PATCAT.

[29] The instruments and the exclusion restrictions identify the probabilities for this model. See Maddala (1983), p. 122-123.

VII. Federal Laboratories and Industrial Research Expenditures

A. Influence of Public-Private Interactions on Industrial R&D

Table 8 studies the determinants of laboratory R&D. The table reports four specifications of laboratory R&D: total; company-financed (less expenditures on federal laboratories); federally financed; and expenditures on federal laboratories. We expect that interactions with federal laboratories would have different effects on these measures. Total laboratory R&D averages the effects across components. Company-financed R&D forms most of budget. It is the part most driven by profitability of the firm's research. Federally funded R&D increases with government support. It is therefore, influenced by characteristics of the firm and laboratory that attract the funding. Although a minor part of budget, expenditures on federal laboratories are the most affected by contact with such laboratories. Thus we are looking for comparative effects of federal laboratory interactions in table 8. We are also interested in whether the average of these effects differs from the effect on patents.

Equations 8.1 and 8.2 fit laboratory budget to variables that measure size and other characteristics. R&D spending is significantly smaller in laboratories that specialize in testing and are jointly housed with manufacturing. Ph.D. scientists to an extent capture size of the laboratory while recent sales of the firm control for firm size and the incentives to perform R&D. Both are linked to increases in R&D.

Holding recent sales constant, R&D in the rest of the firm reduces laboratory R&D, suggesting substitution towards other laboratories. Building on previous research that finds R&D intensity to be unrelated to firm size (Bound et al., 1984), the joint effect of rest of firm R&D and recent sales is positive for laboratory R&D. We impose constancy of R&D intensity by assuming an equal percentage increase in R&D in the rest of the firm and in sales. Then the finding in table 8 of a larger elasticity of laboratory R&D with respect to sales than rest of firm R&D implies that their joint effect is positive for laboratory R&D.

The pattern of government laboratory interactions in 8.1 and 8.2 resembles the pattern for patents in table 5. Government Contractor is insignificant whereas CRADA increases laboratory R&D. As before, on-site federal R&D in closely affiliated federal laboratories has almost no effect on R&D.

Equations 8.3 and 8.4 explore the determinants of company-financed R&D net of expenditures on federal laboratories. Since most R&D is company-financed the results are similar to 8.1 and 8.2. Of the three indicators of

[30] The estimated cut points are 0.22, 0.71, 1.17, 1.62, 1.90, 2.24, 2.58, 3.13 and 3.69.

federal laboratory interaction only CRADA increases company-financed R&D, perhaps reflecting the cost-sharing provisions of cooperative agreements that were discussed in section II of this paper.

Equations 8.5 and 8.6 study federally funded R&D. The estimation method is Tobit analysis since 80% of the laboratories receive no federal funding[31]. Clearly larger firms attract larger amounts of federal funding. In 8.5 both Government Contractor and CRADA contribute to federally funded R&D. Equation 8.6 introduces R&D of closely affiliated federal laboratories. As before, federal laboratory R&D is insignificant.

The Tobit coefficients are much larger than the OLS coefficients. But expected marginal effects in Tobit analysis are the estimated coefficients times the fraction of observations not censored[32]. The marginal effect of CRADA on company-financed R&D is 0.65 in 8.3, but the marginal effect of CRADA on federally funded R&D is $0.2 \times 3.79 = 0.76$ in 8.5. The same comparison holds for the other variables. All the Tobit coefficients must be multiplied by the fraction of observations not censored to obtain expected marginal effects that are comparable to OLS coefficients.

Table 8 concludes with company-financed expenditures by the private laboratories on federal laboratories. Though a minor element of R&D, one would expect a strong reaction of this type of expenditure to public-private interactions, because of its focus on federal laboratory research. The estimation method is again Tobit analysis since expenditures on federal laboratories equal zero for 83% of the observations.

Equations 8.7 to 8.8 contain the results. Equation 8.7 includes Government Contractor and CRADA, while 8.8 adds the logarithm of federal laboratory R&D per research division. Government Contractor is insignificant consistent with the notion that contractor R&D is fully funded by government. CRADA increases expenditures on federal laboratories, consistent with its interpretation as an indicator of joint research. For the first time R&D of federal laboratories contributes significantly, perhaps because larger federal laboratories award larger grants or because they attract more interest from collaborating R&D laboratories. But these effects apply to a minor part of R&D and are concealed in laboratory R&D, as equations 8.1 and 8.2 show.

Similar to the findings for patents table 8 suggests that only CRADA among federal laboratory interactions stimulates company R&D. As a mechanical matter government contracts increase publicly funded R&D. As a

[31] For a discussion of Tobit, see for example Greene (2000), chapter 20.3.

[32] Where β is the Tobit coefficient and $1-\Phi$ is the fraction of observations not censored, the expected marginal effect is $\beta \bullet (1-\Phi)$. Compare this result with OLS, where β is both the regression coefficient and the marginal effect. See Greene (2000), Theorem 20.4 for a proof.

contractual matter and as a result of incentives, firms that participate in CRADAs spend more on their own, receive more government support, and are more energetic in finding out about research in government laboratories.

In order to measure the effect of CRADA we use a formula like (6) for patents. Just as $\log \lambda = x'\beta$, so here $\log R\&D = z'\delta$. We replace mean λ with mean R&D throughout (6), yielding

$$\Delta\overline{R\&D}^{0} \ldots \widetilde{R}\,\widetilde{\&}\,\widetilde{D}^{1} - \overline{R\&D}^{0} = \overline{R\&D}^{0}\left(e^{\delta_j} - 1\right) \tag{12}$$

$\Delta\overline{R\&D}^{0}$ is the mean increase in R&D due to CRADA, $\widetilde{R}\,\widetilde{\&}\,\widetilde{D}^{1}$ is additional R&D in non-recipient laboratories brought about by CRADA, and $\overline{R\&D}^{0}$ is mean R&D in non-recipient laboratories. Superscript 0 stands for the group where CRADA=0, superscript 1 stands for the group where CRADA=1, and δ_j is the coefficient of CRADA. Equation (12) reports the average effect of CRADA using mean R&D of laboratories where CRADA=0 ($\overline{R\&D}^{0}$) as a baseline. Mean R&D in laboratories where CRADA=0 is $\overline{R\&D}^{0}$ =4.48 and $\overline{R\&D}^{1}$ =23.13 where CRADA=1 (see fn. 22). For the CRADA effect we use δ_j =0.5 or 0.6 from 8.4 and 8.5—the results for company-financed R&D and the concept that is most free from federal support and the most reliable for estimating the effect of CRADA. Substituting these numbers into (12), we find that $\Delta\overline{R\&D}^{0}$ =2.90 or 3.69.

To gauge the size of this effect we use a formula that is similar to (7):

$$R_{\Delta\overline{R\&D}^{0}} \ldots \frac{\Delta\overline{R\&D}^{0}}{\overline{R\&D}^{1} - \overline{R\&D}^{0}} \tag{13}$$

This is the fraction of the difference in R&D in laboratories where CRADA=1 (superscript 1) and CRADA=0 (superscript 0) that is due to CRADA itself. We have calculated the numerator of (13) to be 2.90 or 3.69. In addition $\overline{R\&D}^{0}$ =4.48 and $\overline{R\&D}^{1}$ =23.13 (again see fn. 22). Inserting these calculations in (13) we find $R_{\Delta\overline{R\&D}^{o}}$ =0.16 or 0.20. Thus CRADA accounts for 0.16-0.20 of the difference in R&D between the two groups of laboratories. CRADA contributes up to one-fifth of the gap in R&D budget between the two sub-samples. This finding seems sensible given that CRADA may represent several cooperative agreements.

Table 9 further explores the effect of federal laboratory interactions on industrial R&D. As in table 6 we set up a competition between CRADA and alternative indicators of technology transfer to see which dominates.

One difference is that there are now four dependent variables made up of the different types of laboratory R&D in table 8. Table 9 reports eight regressions that are otherwise specified as in table 8. These regressions compare the importance of the other technology transfer indicators (licensing of government patents, inflows of ideas from government laboratories, inflows of government scientists, and use of industry-government technology transfer centers) with that of CRADA. Throughout CRADA has a positive and significant effect on every category of R&D. As before Government Contractor has the same effect on federally funded R&D.

Now consider combined indicators of technology transfer. Recall that ANY is equal to 1 if any of the technology transfer dummies equals 1 and 0 otherwise. ALL is the sum of the five dummies and ranges from 0 to 5, capturing intensity of interactions with federal laboratories. ANY OTHER and ALL OTHER take CRADA out of ANY and ALL. ANY and ALL are significant alone and in combination with Government Contractor in lines 1-4 of the table. But when CRADA is taken out of ANY and ALL in lines 5 and 7, ANY OTHER and ALL OTHER are insignificant in columns (1) and (2), representing total and company-financed R&D. Only in columns (3) and (4), consisting of federally funded R&D and expenditures on federal laboratories, are ANY OTHER and ALL OTHER significant. Lines 6 and 8 enter the Government Contractor variable. ANY OTHER and ALL OTHER are no longer significant in the case of federally financed R&D. However ANY OTHER and ALL OTHER still matter for company expenditures on federal laboratories.

In general ANY and ALL are more often significant in the equations for R&D expenditures than they are in patent equations. And yet, just as in table 6, most of their effect is due to CRADA and Government Contractor. Once these two indicators are accounted for residual indicators of technology transfer (licensing of government patents, inflows of ideas from government laboratories, inflows of government scientists, and use of industry-government technology transfer centers) influence only the minor part of budget devoted to expenditures on government laboratories. This effect disappears from total R&D budget, where ANY OTHER and ALL OTHER are insignificant, showing how small expenditures on federal laboratories are.

B. Influence of Public-Private Interactions on Procurement

We conclude the empirical work by studying the determinants of procurement. In section III we said that CRADAs could stimulate procurement as well as the reverse. To test this idea we estimate Tobit equations in which the logarithm of procurement is the limited dependent variable and laboratory R&D, the importance of science fields

rather than engineering (Science), firm sales, and CRADA are the determinants. Equation (14) reports our first set of results, with t-statistics shown in parentheses.

Log (Procurement)= -18.65+1.01*log (Company R&D) - 2.63*Science + 1.01*log (Firm Sales)
(-5.1) (2.7) (-1.1) (2.5)

(14)

+2.98*CRADA (N=294, Fraction Left Censored= 0.65, Log Likelihood= -437.26)
(2.5)

Also included in this equation, but omitted for brevity, are industry dummies, the logarithm of R&D in the rest of the firm, and laboratory specialization in testing. Equation (14) shows that larger laboratories and firms and laboratories where CRADAs are important all win more procurement dollars, while laboratories oriented towards basic science earn less (though the last effect is insignificant). As in our earlier investigations, equation (15) includes GOVERNMENT CONTRACTOR as well as CRADA:

Log (Procurement)= -17.40+0.96*log (Company R&D) - 2.49*Science + 0.84*log (Firm Sales)
(-5.0) (2.6) (-1.0) (2.1)

(15)

+0.31*CRADA +4.60*GOVERNMENT CONTRACTOR
(0.2) (3.2)

(N=294, Fraction Left Censored= 0.65, Log Likelihood= -432.24)

Thus, while there is some indication from (14) and (15) that CRADA helps to drive procurement, the relationship is not robust. In effect, the causal significance of CRADA is not identified separately from contractor relationships in the same way as it was for industrial patents and R&D.

VIII. Summary and Conclusion

The passage of the Bayh-Dole and Stevenson-Wydler Acts two decades ago transformed technology transfer policy. Bayh-Dole eased restrictions on the private use of inventions funded by government. Stevenson-Wydler Act complemented Bayh-Dole by introducing cooperative research or CRADAs between firms and federal laboratories. Our findings suggest that Stevenson-Wydler and its successors may have had an effect, since CRADAs as we measure them appear to have stimulated industrial patents and company-financed R&D. Moreover, in this paper we find no other channel of technology transfer from federal laboratories that exerts a comparable effect. Our results may suggest that arrangements like CRADAs that strive to ensure effort by both firms and federal laboratories are required for successful technology transfer. But further work is needed to verify the CRADA effect and whether additional policies, especially licensing of federal patents and movements of federal laboratory

scientists into the private sector, also drive the influence of the laboratories. For example, patent licensing and mobility could affect new products and processes produced by firms, rather than company patents or R&D as analyzed here. Also of interest is the influence of CRADAs on the federal laboratories themselves, since the analysis of section III suggests that they also benefit from CRADAs.

We turn now to some unanswered questions. The CRADA effect that we observe is not random. Instead a double selection mechanism operates that yields CRADAs between pairs of firms and federal laboratories. Firms will not apply for CRADAs unless expected returns exceed their expected costs. Likewise federal laboratories choose among applicants and establish acceptance criteria for projects. Therefore, the CRADAs that we observe are likely to be more productive than CRADAs awarded at random. We suspect that firms apply to federal laboratories that they know well, and that federal laboratories select CRADA applicants whose work is relevant and trusted by them. Hence CRADAs spring from long-term relationships between federal laboratories and firms. It follows that a panel of data on collaborations between firms and federal laboratories is needed to expand the study of CRADAs and other policies. The Ordered Probit-Probit equations of table 7 try to get at this, but more evidence is needed.

Eventually one would like to do a cost benefit analysis of CRADAs and other forms of technology transfer from the federal laboratories. But to undertake such an analysis one would have to be able to calculate the stream of producer and consumer's surplus from products and processes that derive from CRADAs, as well as the rates of decay in both forms of surplus. On the cost side one would need to know all the costs incurred by firms in carrying CRADAs to commercialization, including those CRADAs that turned out to be unsuccessful, and likewise the costs of federal laboratories in administering all the CRADAs. More deeply one would like to know which portions of the federal laboratory system are able to sustain a stream of successful CRADAs and other technology transfer and why, including those aspects of contract design that are most successful in ensuring technology transfer. We have scratched the surface of public-private interactions in research, but there is still much to be learned about the factors that determine success and failure of the interactions. Together these constitute a notable social experiment of our own time.

Table 1
Distribution of Firms and R&D Laboratories
by Industry Group of the Parent Firm

Industry Group	SIC Code	Number of Firms	Number of R&D Laboratories*
Chemicals	28	31	59
Machinery	35	37	58
Electrical Equipment	36	33	57
Transportation Equipment	37	14	34
All Industries	___	**115**	**208**

Source: ***Survey of Industrial Laboratory Technologies 1996.*** * The 208 observations represent 220 laboratories or research groups owing to grouping of laboratories by several firms.

Table 2
Characteristics of R&D Laboratories
(Standard Deviations in Parentheses)

Variable	Industrial R&D Laboratories	
	Linked to Federal Laboratories	Not linked to Federal Laboratories
R&D Inputs		
Number of Scientists and Engineers	241.9	77.0
	(563.5)	(261.8)
Number of Ph.D. (or MD) Scientists and Engineers	40.8	5.9
	(160.2)	(18.4)
Current Laboratory R&D Budget (in millions of '87 $)	20.2	8.1
	(52.8)	(26.3)
R&D Outputs		
Patents Granted from the Survey	11.3	5.4
	(29.6)	(5.4)
Patents Granted from the Survey, Augmented by USPTO Patents for the Firm and Laboratory Location	17.5	8.0
	(49.1)	(29.0)

Source: ***Survey of Industrial Laboratory Technologies 1996***.

Table 3
Types of Interactions between R&D Laboratories and Federal Laboratories

Type of Interaction	Percent of Industrial R&D Laboratories Ranking Type of Interaction as Important [a]
Test Facilities in Government Laboratories	32.7
Licensing of Government Patents [b]	15.7
Cooperative Research and Development Agreement (CRADA) [b]	28.4
Inflows of Scientists from Government Labs [b]	14.9
Outflows of Scientists to Government Labs	7.2
Small Business Innovation Research Program (SBIR)	10.6
Government Contractor	26.4
Inflows of Ideas from Government Labs [b]	34.6
Outflows of Ideas to Government Labs	21.2
Industry-Government Technology Transfer Centers [b]	25.0

Source: ***Survey of Industrial Laboratory Technologies 1996***. [a] An interaction is classified as important when it receives a score of 3-5 on a five point Likert scale. Sample consists of all laboratories in the survey that report the data. [b] Indicator of technology transfer.

Table 4
Frequency Distribution of Technology Transfer Indicators, Federal Laboratories to Industrial R&D Laboratories

Number of Technology Transfer Indicators Rated as Important [a]	Percent of All Industrial R&D Labs
0	58.2
1	6.7
2	12.0
3	8.7
4	10.1
5	4.3

Source: ***Survey of Industrial Laboratory Technologies 1996***. [a] The technology transfer indicators are licensing of government patents, cooperative research and development agreements (CRADAs), inflows of scientists from government labs, inflows of ideas from government labs, and participation in industry-government technology transfer centers, as noted in Table 3. An indicator of technology transfer is rated as important if it receives a score of 3-5 on a 5 point Likert scale. Sample consists of all laboratories that report the data.

Table 5
Patents Issued to Industrial Laboratories
(Asymptotic t-Statistics in Parentheses)

Variable or Statistic	Patents Granted				Augmented Patents			
	Eq. 5.1	Eq. 5.2	Eq. 5.3	Eq. 5.4	Eq. 5.5	Eq. 5.6	Eq. 5.7	Eq. 5.8
Estimation Method	Negative Binomial Regression							
Year, Industry Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Lab is primarily a Testing Facility (1 if yes, 0 if no)	-1.17 (-1.9)	-1.02 (-1.7)	-1.05 (-1.7)	-1.01 (-1.7)	-1.35 (-2.1)	-1.25 (-2.0)	-1.26 (-2.0)	-1.31 (-2.1)
Lab Housed With Manufacturing (1 if yes, 0 if no)	0.19 (1.1)	0.11 (0.7)	0.15 (0.9)	0.19 (1.0)	0.04 (0.2)	0.0 (0.0)	0.02 (0.1)	0.03 (0.2)
Log (Laboratory R&D budget)	0.78 (14.2)	0.75 (13.8)	0.76 (14.0)		0.71 (13.2)	0.68 (12.7)	0.69 (12.9)	
Log (Company-Financed Laboratory R&D Budget)				0.73 (12.5)				0.66 (11.4)
Log (Federally-Funded Laboratory R&D Budget)				0.03 (0.5)				0.03 (0.5)
Log (R&D in the Rest of the Firm)	0.09 (4.7)	0.08 (4.7)	0.08 (4.6)	0.06 (3.6)	0.08 (4.2)	0.08 (4.2)	0.08 (4.2)	0.06 (3.3)
Government Contractor (1 if yes, 0 if no)	-0.12 (-0.6)		-0.38 (-1.9)	-0.54 (-2.1)	-0.23 (-1.2)		-0.48 (-2.2)	-0.49 (-1.7)
CRADA (1 if yes, 0 if no)		0.48 (2.9)	0.60 (3.4)	0.48 (2.2)		0.34 (1.9)	0.52 (2.7)	0.46 (1.9)
Log (Value of Procurement Near the Laboratory)	0.02 (0.7)	0.01 (0.2)	0.02 (0.7)	0.00 (0.1)	0.06 (2.2)	0.05 (1.9)	0.06 (2.2)	0.06 (2.0)
Log (Value of Procurement in the Rest of the Firm)	-0.05 (-2.1)	-0.05 (-2.2)	-0.05 (-2.1)	-0.06 (-2.4)	-0.05 (-1.9)	-0.05 (-2.0)	-0.05 (-1.9)	-0.05 (-2.0)
Patents Imputed from USPTO for Firm and Location (1 if yes, 0 if no)					0.49 (2.0)	0.59 (2.4)	0.52 (2.2)	0.75 (2.7)
Log (R&D in Closely Affiliated Gov. Labs per Directorate)				0.03 (0.7)				0.00 (0.0)
Number of Observations	268	268	268	243	306	306	306	274
Log Likelihood	-618.5	-614.6	-613.0	-527.3	-755.8	-754.7	-752.2	-643.2

Sources: ***Survey of Industrial Laboratory Technologies 1996*** and ***Survey of Government Laboratory R&D 1998***.

Table 6
Patents Issued to Industrial Laboratories
Variations on the Federal Laboratory Interactions
(Asymptotic t-Statistics in Parentheses)

Line Number	Federal Laboratory Interactions	Coefficients (t-Statistics)
1	ANY (1 if yes, 0 if no)	0.22 (1.4)
2	ANY (1 if yes, 0 if no)	0.40 (2.1)
	Government Contractor (1 if yes, 0 if no)	-0.41 (-1.9)
3	ALL (Range from 0 to 5)	0.10 (2.1)
4	ALL (Range from 0 to 5)	0.14 (2.8)
	Government Contractor (1 if yes, 0 if no)	-0.42 (-2.0)
5	ANY OTHER (1 if yes, 0 if no)	-0.13 (-0.6)
	CRADA (1 if yes, 0 if no)	0.52 (2.4)
6	ANY OTHER (1 if yes, 0 if no)	0.01 (0.0)
	CRADA (1 if yes, 0 if no)	0.59 (2.7)
	Government Contractor (1 if yes, 0 if no)	-0.44 (-2.1)
7	ALL OTHER (Range from 0 to 4)	0.01 (0.1)
	CRADA (1 if yes, 0 if no)	0.42 (1.9)
8	ALL OTHER (Range from 0 to 4)	0.04 (0.5)
	CRADA (1 if yes, 0 if no)	0.53 (2.4)
	Government Contractor (1 if yes, 0 if no)	-0.46 (-2.3)

Sources: ***Survey of Industrial Laboratory Technologies 1996*** and ***Survey of Government Laboratory R&D 1998***.

Table 7
Two Equation, Maximum Likelihood Estimates of Patents Issued and CRADAs
(Asymptotic t-Statistics in Parentheses)

Variable or Statistic	PATCAT	CRADA	PATCAT	CRADA
	Eq. 7.1	Eq. 7.2	Eq. 7.3	Eq. 7.4
Estimation Method	Ordered Probit	Probit	Two Eq. Maximum Likelihood	
Year, Industry Dummies	Yes	Yes	Yes	Yes
Lab Housed With Manufacturing (1 if yes, 0 if no)	0.17 (1.1)	0.41 (1.6)	0.15 (1.0)	0.41 (1.6)
Log (Laboratory R&D Budget)	0.65 (11.4)	0.13 (1.6)	0.64 (10.6)	0.13 (1.6)
Log (R&D in the Rest of the Firm)	0.07 (4.0)		0.06 (4.0)	
CRADA (1 if yes, 0 if no)	0.53 (3.5)		0.67 (2.6)	
Log (Value of Procurement Near the Laboratory)	0.01 (0.4)		0.01 (0.4)	
Log (Value of Procurement in the Rest of the Firm)	-0.04 (-2.1)		-0.04 (-2.0)	
Government Contractor (1 if yes, 0 if no)		0.66 (2.5)		0.66 (2.5)
Inflows of Ideas from Government Labs (1 if yes, 0 if no)		1.00 (3.2)		0.99 (3.2)
Inflows of Scientists from Government Labs (1 if yes, 0 if no)		0.47 (1.5)		0.49 (1.5)
Licensing of Government Patents (1 if yes, 0 if no)		0.91 (3.3)		0.89 (3.3)
Test Facilities in Government Laboratories (1 if yes, 0 if no)		0.41 (1.5)		0.40 (1.4)
Industry-Government Technology Transfer Centers (1 if yes, 0 if no)		0.04 (0.1)		0.07 (0.3)
Log Likelihood	-450.6	-89.9	-540.3	
Cross-Equation Correlation			-0.14 (-0.7)	

Sources: ***Survey of Industrial Laboratory Technologies 1996*** and ***Survey of Government Laboratory R&D 1998***.
The number of observations is N=268.

Table 8
R&D Expenditures of Industrial Laboratories,
Subdivided by Source of Funding and Function
(t-Statistics in Parentheses)

Variable or Statistic	Log (Laboratory R&D Budget)		Log (Company-Financed Laboratory R&D Budget)		Log (Federally-Funded Laboratory R&D Budget)		Log (Expenditures On Federal Laboratory R&D)	
	Eq. 8.1	Eq. 8.2	Eq. 8.3	Eq. 8.4	Eq. 8.5	Eq. 8.6	Eq. 8.7	Eq. 8.8
Estimation Method	OLS		OLS		OLS		Tobit	
Year, Industry Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Lab is primarily a Testing Facility (1 if yes, 0 if no)	-0.60 (-1.6)	-0.60 (-1.6)	-0.62 (-1.6)	-0.61 (-1.6)	1.24 (0.6)	1.18 (0.5)	3.31 (1.6)	3.19 (1.5)
Lab Housed With Manufactu-Ring (1 if yes, 0 if no)	-0.82 (-5.1)	-0.82 (-5.1)	-0.81 (-4.8)	-0.82 (-4.9)	1.77 (1.8)	1.68 (1.7)	-0.59 (-0.7)	-0.55 (-0.7)
Log (Number of Ph.D. scientists in the Lab)	0.15 (7.7)	0.l5 (7.7)	0.14 (6.6)	0.14 (6.6)	0.41 (3.4)	0.41 (3.4)	0.22 (1.9)	0.21 (1.9)
Log (R&D in the Rest of the Firm)	-0.07 (-3.5)	-0.06 (-3.4)	-0.08 (-3.7)	-0.08 (-3.6)	-0.04 (-0.3)	-0.06 (-0.5)	-0.06 (-0.5)	-0.09 (-0.8)
Log (Recent Sales of the Firm)	0.31 (6.0)	0.36 (6.0)	0.30 (5.7)	0.30 (5.7)	0.16 (0.5)	0.17 (0.6)	0.78 (2.7)	0.78 (2.7)
Government Contractor (1 if yes, 0 if no)	-0.14 (-0.6)	-0.07 (-0.3)	-0.24 (-1.0)	-0.18 (-0.7)	5.68 (5.3)	5.30 (4.9)	1.30 (1.3)	1.01 (1.0)
CRADA (1 if yes, 0 if no)	0.58 (2.8)	0.70 (3.0)	0.52 (2.3)	0.62 (2.4)	3.20 (3.0)	2.82 (2.6)	6.28 (5.6)	5.20 (4.5)
Log (R&D in Closely Affiliated Government Labs per Directorate)		-0.05 (-1.1)		-0.04 (-0.9)		0.24 (1.3)		0.39 (2.2)
Log (Value of Procurement Near the Laboratory)	0.04 (1.4)	0.04 (1.3)	0.03 (1.1)	0.03 (1.0)	0.22 (1.7)	0.22 (1.7)	-0.11 (-0.8)	-0.10 (-0.7)
Log (Value of Procurement in the Rest of the Firm)	0.03 (1.4)	0.03 (1.4)	0.04 (1.5)	0.04 (1.5)	0.12 (1.1)	0.12 (1.1)	-0.17 (-1.3)	-0.17 (-1.4)
Number of Observations	280	280	263	263	266	266	271	271
Adjusted R^2	0.54	0.54	0.47	0.47	--	--	--	--
Root MSE	1.22	1.22	1.24	1.25	3.49	3.46	4.15	4.06

Table 8
R&D Expenditures of Industrial Laboratories,
Subdivided by Source of Funding and Function
(t-Statistics in Parentheses)

Variable or Statistic	Log (Laboratory R&D Budget)		Log (Company-Financed Laboratory R&D Budget)		Log (Federally-Funded Laboratory R&D Budget)		Log (Expenditures On Federal Laboratory R&D)	
	Eq. 8.1	Eq. 8.2	Eq. 8.3	Eq. 8.4	Eq. 8.5	Eq. 8.6	Eq. 8.7	Eq. 8.8
Fraction of Observations that are Left-Censored	--	--	--	--	0.83	0.83	0.80	0.80
Log Likelihood	--	--	--	--	-151.5	-150.7	-208.5	-206.1

Sources: ***Survey of Industrial Laboratory Technologies 1996*** and ***Survey of Government Laboratory R&D 1998***.

Table 9
R&D Expenditures of Industrial Laboratories
Variations on Federal Laboratory Interactions
(t-Statistics in Parentheses)

Line Number	Federal Laboratory Interactions	(1) Log (Laboratory R&D Budget) Coefficients (t-Statistics)	(2) Log (Company Financed Laboratory R&D Budget) Coefficients (t-Statistics)	(3) Log (Federally Funded Laboratory R&D Budget) Coefficients (t-Statistics)	(4) Log (Laboratory Expenditures on Federal Laboratories) Coefficients (t-Statistics)
1	ANY (1 if yes, 0 if no)	0.41 (2.5)	0.32 (1.9)	9.38 (5.7)	7.48 (6.4)
2	ANY (1 if yes, 0 if no)	0.31 (1.5)	0.33 (1.5)	3.96 (2.6)	7.53 (5.9)
	Government Contractor (1 if yes, 0 if no)	0.18 (0.8)	-0.02 (-0.1)	5.96 (4.7)	-0.09 (-0.1)
3	ALL (Range from 0 to 5)	0.18 (3.6)	0.15 (2.9)	2.24 (5.8)	1.95 (6.8)
4	ALL (Range from 0 to 5)	0.18 (2.9)	0.18 (2.8)	0.67 (1.8)	1.93 (6.1)
	Government Contractor (1 if yes, 0 if no)	0.03 (0.1)	-0.19 (-0.8)	6.96 (5.4)	0.14 (0.1)
5	ANY OTHER (1 if yes, 0 if no)	0.16 (0.8)	0.15 (0.7)	4.39 (3.4)	3.51 (3.4)
	CRADA (1 if yes, 0 if no)	0.56 (2.5)	0.45 (1.9)	5.77 (4.6)	4.14 (4.1)
6	ANY OTHER (1 if yes, 0 if no)	0.18 (0.8)	0.24 (1.0)	0.86 (0.6)	3.61 (3.3)
	CRADA (1 if yes, 0 if no)	0.58 (2.5)	0.51 (2.1)	3.64 (3.2)	4.21 (4.0)
	Government Contractor (1 if yes, 0 if no)	-0.05 (-0.2)	-0.24 (-0.9)	5.82 (4.5)	-0.29 (-0.3)
7	ALL OTHER (Range from 0 to 4)	0.07 (0.9)	0.08 (0.9)	0.86 (1.9)	1.45 (3.9)
	CRADA (1 if yes, 0 if no)	0.54 (2.4)	0.41 (1.7)	6.76 (4.9)	3.65 (3.7)
8	ALL OTHER (Range from 0 to 4)	0.08 (0.9)	0.11 (1.2)	-0.13 (-0.3)	1.46 (3.8)
	CRADA (1 if yes, 0 if no)	0.56 (2.3)	0.48 (1.9)	3.89 (3.3)	3.70 (3.6)
	Government Contractor (1 if yes, 0 if no)	-0.04 (-0.2)	-0.23 (-0.9)	6.43 (5.1)	-0.14 (-0.2)

Sources: ***Survey of Industrial Laboratory Technologies 1996*** and ***Survey of Government Laboratory R&D 1998***.

References

Adams, James D., **Survey of Industrial Laboratory Technologies 1996**, processed, Department of Economics, University of Florida, 1997.

_____, **Survey of Government Laboratory R&D 1998**, processed, Department of Economics, University of Florida, 1998.

_____, "The Structure of Firm R&D, the Factor Intensity of Production, and Skill Bias," **The Review of Economics and Statistics** 81 (August 1999): 499-510.

_____, "Learning and Internal Research: The Two Faces of R&D Revisited," Working Paper, University Of Florida, September 2002.

_____, and Adam B. Jaffe, "Bounding the Effects of R&D: An Investigation Using Matched Firm and Establishment Data," **RAND Journal of Economics** 27 (1996): 700-721.

Aghion, Philippe, and Jean Tirole, "The Management of Innovation," **Quarterly Journal of Economics** 109 (November 1994): 1185-1209.

Bound, John, Clint Cummins, Zvi Griliches, Bronwyn H. Hall, and Adam B. Jaffe, "Who Does R&D and Who Patents?" in Zvi Griliches, ed., **R&D, Patents, and Productivity**, Chicago: University of Chicago Press for NBER, 1984.

Cockburn, Iain, and Rebecca Henderson, "Public-Private Interaction in Pharmaceutical Research," **Proceedings of the National Academy of Sciences** 93 (1996): 12725-12730.

Cohen, Linda R., and Roger G. Noll, "The Future of the National Laboratories," **Proceedings of the National Academy of Sciences** 93 (1996): 12678-12685.

Cohen, Wesley M., and Daniel A. Levinthal, "Innovation and Learning: the Two Faces of R&D," **The Economic Journal** 99 (1989): 569-596.

Defense Technical Information Center, **Department of Defense In-House RDT&E Activities**, U.S. Army Materiel Development and Readiness Command, Alexandria, Virginia: various years.

Directory of American Research and Technology, 31st Edition, New Providence, New Jersey: R.R. Bowker, 1997.

Evenson, Robert, and Yoav Kislev, "Research and Productivity in Wheat and Maize," **Journal of Political Economy** 81 (1973): 1309-1329.

"Extreme Measures," **The Economist** 158 (June 23, 2001).

Feldman, Maryann P., "The Entrepreneurial Event Revisited: Firm Formation in a Regional Context," **Industrial And Corporate Change** 10 (December 2001): 861-891.

Gould, William, and William Sribney, **Maximum Likelihood Estimation with STATA**, 1st ed., College Station, Texas: STATA Press, 1999.

Greene, William H., **Econometric Analysis**, 4th Ed.: Upper Saddle River, New Jersey: Prentice-Hall, 2000.

Griliches, Zvi, and Ariel Pakes, "Patents and R&D at the Firm Level: A First Look," in Zvi Griliches, editor, **R&D, Patents, and Productivity**, Chicago, Illinois: University of Chicago Press for NBER, 1984.

Grossman, Sanford J., and Oliver Hart, "The Costs and Benefits of Ownership: A Theory of Vertical and Lateral Integration," **Journal of Political Economy** 94 (August 1986): 691-719.

Ham, Rose Marie, and David C. Mowery, "Improving the Effectiveness of Public-Private R&D Collaboration: Case Studies at a U.S. Weapons Laboratory," **Research Policy** 26 (1998): 661-675.

Hart, Oliver, Andrei Shleifer, and Robert W. Vishny, "The Proper Scope of Government," **Quarterly Journal of Economics** 112 (November 1997): 1127-1162.

Hausman, Jerry, Bronwyn Hall, and Zvi Griliches, "Economic Models for Count Data with an Application to the Patents-R&D Relationship," **Econometrica** 52 (1984): 909-938.

Heckman, James J., "Dummy Endogenous Variables in a Simultaneous Equation System," **Econometrica** 46 (1978): 931-959.

Holmstrom, Bengt, and John Roberts, "The Boundaries of the Firm Revisited," **Journal of Economic Perspectives** 12 (Fall 1998): 73-94.

Jaffe, Adam B., and Josh Lerner, "Reinventing Public R&D: Patent Policy and the Commercialization of National Laboratory Technologies," **Rand Journal of Economics** 32 (Spring 2001): 167-198.

Jensen, Richard, and Marie Thursby, "Proofs and Prototypes for Sale: The Licensing of University Inventions," **American Economic Review** 91 (March 2001): 240-259.

Johnson, Norman L., and Samuel Kotz, **Discrete Distributions**, Boston: Houghton-Mifflin, 1969.

Klette, Tor Jakob, Jarle Moen, and Zvi Griliches, "Do Subsidies to Commercial R&D Reduce Market Failures? Microeconomic Evaluation Studies," **Research Policy** 29 (April 2000): 471-496.

Krugman, Paul, **The Age of Diminished Expectations**, revised and updated edition, Cambridge, Massachusetts:

MIT Press, 1994.

Maddala, G. S., **Limited-Dependent and Qualitative Variables in Econometrics**, Cambridge, UK: Cambridge University Press, 1983.

Markusen, Ann, and Michael Oden, "National Laboratories as Business Incubators and Region Builders," **Journal of Technology Transfer** 21 (1996): 93-108.

Mowery, David C., and Nathan Rosenberg, **Paths of Innovation: Technological Change in 20th Century America**. New York: Cambridge University Press, 1998.

National Aeronautics and Space Administration, Office of General Counsel, "Space Act Agreements," 2001, http://www.hq.nasa.gov/ogc/samanual.html.

National Research Council, Board on Science, Technology, and Economic Policy, **Trends in Federal Support of Research and Graduate Education.** Washington, D.C., National Academy Press, 2001.

National Science Board, **Science and Engineering Indicators, 1998**. Washington D.C., U.S. Government Printing Office, 1998.

National Science Foundation, **Federal Funds for Research and Development**. Washington D.C., U.S. Government Printing Office: various years.

Olley, G. Steven, and Ariel Pakes, "The Dynamics of Productivity in the Telecommunications Industry," **Econometrica** 64 (1996): 1263-1298.

Schacht, Wendy H., "Patent Ownership and Federal Research and Development (R&D): A Discussion on the Bayh-Dole Act and the Stephenson-Wydler Act," Washington, DC: Congressional Research Service, Document RL30320, December 11, 2000.

Scherer, F. Michael, "Firm Size, Market Structure, Opportunity, and the Output of Patented Inventions," **American Economic Review** 55 (December 1965): 1097-1123.

Shleifer, Andrei, "State versus Private Ownership," **Journal of Economic Perspectives** 12 (Fall 1998): 133-150.

Standard and Poor 's Compustat, Englewood, Colorado: McGraw-Hill, 1994.

U.S. General Accounting Office, **GAO/RCED/NSIAD-96-78R, Federal R&D Laboratories**. Washington D.C., U.S. Government Printing Office, 1996.

U.S. Department of Commerce, Technology Administration, Office of Technology Policy, **Tech Transfer 2000: Making Partnerships Work**. Washington D.C., U.S. Government Printing Office, 2000.

U.S. National Institutes of Health, Office of Technology Transfer, “CRADAs and MTAs,” 2001, http://ott.nih.gov/NewPages/crada-mn.html

U.S. Patents Database, Baltimore, Maryland: Community of Science, Inc., 1999.