GOVERNMENT R&D SUBSIDY, ECONOMIC INCENTIVES AND KNOWLEDGE SPILL-OVERS

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ABSTRACT

New public R&D programs attempt to encourage innovation and economic growth by supporting projects with the potential to generate high social rates of return. Using data on proposed projects and post application performance, we estimate the extent to which projects that received funding exhibited behaviors that the literature associates with knowledge spillovers. We find that projects that received subsidies were more likely to have attributes that provide greater pathways for knowledge spillovers such as participation in new research joint ventures and connections to a large number of other firms. Further, we find that government awards provide a signaling effect for subsequent R&D investment by other sources. Our results suggest that government R&D funding may have a positive and previously undocumented effect on private firm behavior and subsequent economic growth.

Keywords: R&D, government R&D subsidy, innovation, knowledge spillovers

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Investments in research and development (R&D) yield substantial benefits in terms of innovation, productivity gains, and subsequent economic growth (Griliches 1994). Market forces provide firms with incentive to invest in R&D; however, the non-rival nature of the knowledge created makes it difficult for firms to fully appropriate the resulting returns (Nelson 1959; Arrow 1962). Economists debate the magnitude of knowledge spillovers, yet empirical studies conclude that knowledge spillovers are positive and important; the social benefits from R&D are substantially greater than the private return captured by the innovating firm (Griliches 1995). The existence of this market failure is one of the primary justifications for government R&D subsidies.

When implemented, however, government policy tends to generate perverse incentives. Empirical studies find that firms appear to substitute government funding for their own investment, suggesting that government subsidies displace private investment (see, David, Hall and Toole 2000 for a review). In addition, government agents face a difficult task selecting, *ex ante*, those projects that will generate a high social return (Jaffe 1997). There may be a principal-agent problem favoring the selection of projects that will make the program appear successful rather than attempting the task of selecting projects that may generate high social rates of return.

Spence (1984) finds that R&D subsidies are an effective public policy in markets where R&D spillovers are high. While all R&D activity generates spillovers, there is variation in the extent to which firms realize their benefits (Jaffe 1986). In large part, firms' R&D strategy may explain differences in both the absorption and diffusion of knowledge spillovers (Cohen and Levinthal 1989; Cockburn and Henderson 1998; Lim 2000, among others). For example, firms may voluntarily engage in strategies that would increase the spillover potential of their R&D projects or, conversely elect to pursue innovation in isolation and secrecy. To the extent that firms are engaged in collaborative R&D projects, connected to other firms and to universities, and willing to engage in sharing their research results, we expect that knowledge spillovers and the associated social rates of return would increase.

New generations of government programs attempt to encourage economic growth through R&D subsidies. Jaffe (1997) and Trajtenberg (2001) suggest that these new programs may best achieve their mandate by selecting projects to subsidize that have the greatest potential to create knowledge spillovers. This paper makes three contributions to our understanding of government R&D subsidies. First, we develop a set of project characteristics that the literature suggests would generate knowledge spillovers and thus would be associated with increasing the social benefit of an R&D project. Second, we use these measures to test whether projects awarded subsidies are more likely to generate knowledge spillovers than the counterfactual group of firms that applied for, but were not awarded, subsidies. By analyzing all applicants, we reduce the problem of selection bias noted with prior studies of R&D subsidies (Klette, Moen and Griliches 2000).

Knowledge spillovers are not the only factor that accounts for under investment in R&D. Capital market imperfections may also discourage the funding of socially desirable R&D projects. Potential investors face a large number of projects and it is difficult to assess project quality and investment potential (Fried and Hirsch 1994). The award of a government subsidy may certify that a project has merit and increase subsequent private investment (Lerner 1999). Thus, third, we follow firms one year after the award decision and estimate the effect of government funding on the subsequent ability to raise additional money for R&D.

Contrary to the prior literature, we find that the government is selecting projects with greater ability to generate substantial public benefits, even after controlling for technical quality. Government agents select projects with characteristics associated with increased knowledge spillovers. Our examination of a comparison group of projects shows that in the absence of government funding, firms do not proceed with the projects on their own or scale back their effort. Finally, the award itself confers 'a halo' that signals others to invest in these projects. In sum, the evidence suggests that government subsidies increase private investment in R&D and offer incentives to increase the efficiency of the national system of innovation.

Measuring R&D Project Potential for Knowledge Spillovers

A substantial literature concludes that when government subsidizes firm R&D, a displacement or substitution effect occurs and firms spend less on R&D than if the government had not intervened.[1] David, Hall, and Toole (2000) and Guellec and von Pottelsbughe (2000) review the evidence from econometric studies and conclude that this substitution effect is due to the predominance of government mission agency spending which is a very special case of government R&D subsidies. Mission agencies, such as the Department of Defense and Department of Health and Human Services have very focused research agenda with limited commercial potential.[2] In the U.S., these two agencies account for over seventy percent of government R&D spending (National Science Board 2000: Appendix Table 2-23.). Mission agency R&D contracts often carry expectations of long term contracting relationships with follow-on funding or procurement contracts (Cohen 1994). Consequently, firms undertaking contract R&D for the government have found a niche and have no incentive to spend their own funds developing products.[3] The new evidence that David, Hall and Toole (2000) present suggests that crowding out is not a general feature of all government R&D subsidies but is rather an artifact of certain types of program incentives that induce firms to reduce their own R&D funding.

There will always be tremendous *ex ante* uncertainty about the private and social returns to R&D projects.[4] However, it should be possible to identify generic features that tend, on average, to be associated with a greater likelihood of knowledge spillovers (Jaffe 1996). Cohen and Levinthal (1989, 1990) coin the term 'absorptive capacity' to reflect the dual nature of R&D investment: firm investment in R&D provides internal technological capacity that also allows firms to exploit external knowledge. Cockburn and Henderson (1998) point out that understanding knowledge spillovers requires examining firms' connections to other organizations. While absorptive capacity describes a stock of knowledge, knowledge spillover implies a more dynamic process involving the flow of knowledge. Thus, to realize the potential of knowledge spillovers requires connections between organizations. Leyden and Link (1991) and David, Mowery and Steinmueller (1992) suggest that spillover channels or pathways between organizations, could raise the expected social rates of return on commercial R&D projects. Formal R&D partnerships may be one type of spillover pathway while simpler linkages, such as those forged through supplier/customer relationships, professional associations, and mobile human capital, may be another.

Katz (1986) demonstrates that forming cooperative R&D projects internalizes knowledge spillovers among the participants in most product markets.[5] Research joint ventures provide voluntary spillover pathways that lower the cost of knowledge diffusion (Katz and Ordover 1990). Cooperative R&D projects further enhance the welfare effects to the economy by avoiding duplication of effort or inefficient patent races (Reinganum 1989) and providing incentives for incorporating differential expertise and sharing specific assets (Mowery 1983).

The management strategy literature analyzes cooperative R&D projects as voluntary, reciprocal information sharing mechanisms that enhance firm learning and subsequent performance (c.f., Doz, 1996; Hamel, 1991; Harrigan, 1988; Khanna, Gulati, and Nohria, 1998). Branstetter and Sakakibara (2000) find that R&D consortia are most effective, in terms of joint productivity, when they focus on basic research. To the extent that government programs reduce the transaction costs of establishing R&D partnerships in new technological areas, the government subsidy enhances the transfer of knowledge among firms.

In addition to formal research consortia, firms have other less formal and diverse relationships to other organizations that involve sharing knowledge and may provide pathways for spillovers. Organizational theorists argue that the sheer number of such linkages alone may increase a firm's opportunity to learn something new from other organizations (Powell, Koput and Smith-Doer, 1996). A large number of connections to other organizations also indicate that the firm may be an important, central node in the circulation of knowledge throughout a broader network (Granovetter, 1994). The two relevant organizations that would form such pathways for knowledge spillovers are universities and other firms.

Universities are a source of knowledge that may be applied to a broad-range of industrial problems (Mowery and Rosenberg, 1993). Cockburn and Henderson (1998) find that the degree to which firms are connected to universities is important for realizing knowledge spillovers. Gittelman and Kogut (2000) demonstrate that exchanges between university and industry scientists as measured by joint publications have a positive impact on firms' innovative output. Firm relationships with universities form a continuum from formal technology transfer such as licenses or sponsored research to informal exchanges involving friendship networks or serendipitous exchanges.

Linkages to other firms, notably suppliers and customers but also to other organizations with less formal ties provide knowledge spillover pathways. Von Hippel (1988; 1998) demonstrates that downstream users of a technology are a source of knowledge relevant to further R&D and product development. These ideas are often shared in informal ways and reflect personal connections. Similarly, Sako (1994) and Teece (1992) find that connections with suppliers work in similar ways. Lim (2000) provides a detailed empirical examination of electronics and semiconductors and concludes that the capacity of a firm to absorb knowledge spillovers is a function of connectedness to other firms. Similarly, Glasmeier (1991) shows that limited ties to other organizations inhibit learning and innovation. In general, the greater the numbers of links to other organizations, the more pathways exist for potential knowledge spillovers.

Paradoxically, in order to gain access to the knowledge developed in other organizations, a firm has to be willing to trade its own knowledge. Firms may attempt to keep knowledge within the firm even though knowledge protection is costly, and at early stages it is difficult to determine what is valuable and worth protecting (Zeckhauser 1996). Firms employ different strategies to restrict access to their R&D activities (Cohen, Nelson, and Walsh 2000; Levin, Klevorick, Nelson, and Winter 1987). Liebeskind (1996) argues that such efforts are not only costly and difficult to enforce but they also isolate firms from opportunities to benefit from knowledge exchanges. Grindley and Teece (1997) note that trading intellectual property through cross licensing has become common among electronics and semiconductor firms; firms engage in reciprocal sharing and innovation and the entire industry benefits. To the extent that a firm demonstrates greater willingness to share its results with other firms, the potential for R&D spillovers will increase.

In addition, R&D projects that are more basic in nature are expected to yield results that produce greater knowledge spillovers. Our contemporary understanding of the innovation process, based on a chain linked model of knowledge flows, suggests that practical application and use of a technology may generate new applications and ideas that dictate the need for fundamental research (Kline and Rosenberg, 1987). These new research areas would not be part of the firm's core competency but would be basic inquiries that might allow the firm to extend its expertise. Since the intangible results from basic inquiry are more difficult to protect there may be a higher spillover potential.

Data Source and Methodology

Our empirical test employs data about applicants to the 1998 competition to the Advanced Technology Program (ATP) of the U.S. National Institute of Standards (NIST). This program represents one of the public R&D programs that attempts to foster economic growth by increasing the total amount of R&D conducted in the U.S. economy (Jaffe 1996). The program depends on the initiative of industry to define proposed research projects and requires private firms to invest their own funds in a one to one match for the government R&D subsidy. The program carries no expectation of future funding and the agency is not involved in procurement contracting thus eliminating the preserve incentives that David, Hall and Toole (2000) associate with crowding out. A review panel of independent technical experts and industry specialists evaluates every proposal on its scientific merit and economic potential. The program is highly selective and fewer than 20 percent of proposed projects are awarded funding annually.

The ultimate long-term goal of the program is to achieve greater productivity growth in the economy as a whole through technical advances that become incorporated in industrial processes, new products, and services.[6] Jaffe (1997: 18) concludes that the ability to select and subsidize projects with high knowledge spillovers is important to achieving the agency mission: "In order to be effective in achieving its statutory objectives, the ATP must try to determine which projects proposed to it will generate large spillovers and which will not." Thus, the program provides an ideal test case for our purposes.

To collect data we designed a telephone survey instrument that was reviewed and approved by the U.S. Office of Management and Budget and the Johns Hopkins University Committee on the Use of Human Subjects.[7] Before the interviews, we followed standard survey method procedures, and sent a letter to explain the purpose of the survey. The letter identified the ATP as the sponsor of the study and contained a statement of confidentiality and assurance that responses to any of the survey questions would remain anonymous, and would not be publicly released in any form that would identify a specific individual or company. The letter included a list of questions that the respondent might find helpful to have in advance of the telephone interview.

The telephone interview with the project Principal Investigator required 20-30 minutes to complete.[8] The survey results were matched to independent sources to verify employment, financing, and the company founding date. Administrative records from the ATP provided the technology area of the proposal, the results of the ATP proposal review process, the technical and business scores, and the number of prior applications and the number of prior awards that the firm received from the government agency. These will be used as control variables in our regressions.

Table 1: Descriptive Statistics,

Mean (standard deviation)	All Firms	Firms Receiving Subsidy	Firms Not Receiving Subsidy
Dependent Variable: Probability of Winning an Award			
Award Status	0.49		
	(0.50)		
Project Characteristics			
New Partners*	0.66	0.82	0.52
	(1.05)	(1.33)	(0.66)
No Prior Plan to develop Technology*	0.36	0.55	0.18
	(0.73)	(0.93)	(0.39)
Spillover Mechanisms			
University Linkages Index	2.08	2.22	1.95
	(1.67)	(1.67)	(1.66)
Business Linkages Index	4.10	4.50	3.72
	(3.49)	(3.79)	(3.15)
Willingness to Share Research Results*	0.25	0.30	0.19
	(0.43)	(0.46)	(0.39)
Prior Experience with the Program			
First Application to ATP	0.50	0.48	0.51
	(0.50)	(0.50)	(0.50)
Number of Prior ATP Awards	0.56	0.63	0.49
	(1.47)	(1.23)	(1.68)
Proposal Effort	$27,669	$27,392	$27,930
	(35,943)	(33,828)	(37,969)
Industry Control Variables			
Advanced Materials Dummy	0.33	0.29	0.37
	(0.47)	(0.46)	(0.49)
Biotech Dummy	0.13	0.16	0.11
	(0.34)	(0.37)	(0.31)
Electronics Dummy*	0.41	0.48	0.34
	(0.49)	(0.50)	(0.48)
Manufacturing Dummy	0.08	0.01	0.11
	(0.26)	(0.20)	(0.31)
Controls for Project Quality			
Maximum Technical Reviewer Score*	8.27	9.12	7.42
	(1.95)	(0.73)	(2.38)
Maximum Business Reviewer Score*	7.95	8.72	7.18
	(1.98)	(1.03)	(2.38)
Number of Cases	240	118	122

* A t-test for equality of the means for the two categories of firms reveals statistically significant differences for these variables.

We surveyed 100 percent of the firms that received a subsidy and a random sample of 50 percent of the firms that applied to the 1998 ATP competition but did not receive an R&D subsidy. The effective response rate was 61 percent for a total of 240 cases. We completed interviews with 118 winners for an 81 percent response rate (118 completed interviews/147 firms awarded subsidies). For the non-winners, we discovered that within one year there were fortynine cases that we could not interview, either because the company no longer existed (twenty-three cases) or because the person responsible for preparing the proposal was no longer employed at the company and the company was not pursuing any aspect of the R&D project (twenty-six cases). We adjusted our response rate accordingly. We completed interviews for 122 non-winners, for a 50 percent response rate (122 completed interviews/ (297 non-subsidied firms – 49 defunct cases)).

Descriptive statistics for the data are provided in Table 1. Program status is a binary variable, equal to one if the firm received the R&D subsidy and zero otherwise. The survey asked firms if the project involved a new R&D partnership. If the answer was yes, then the variable *New R&D Partnership* is equal to 1. We also asked whether the technical area represented a research topic that had not been part of the firm's R&D plans during the previous two-year period. If the answer indicated that topic was new to the firm, the variable *New R&D Direction* is equal to one. An affirmative answer to either a new R&D partnership or the pursuit of a project area that had not previously been included in the firm's R&D portfolio, suggests that the subsidy would underwrite the risk of establishing a partnership or exploiting a new technical area.

The survey asked about connections to other organizations that would form spillover pathways. Before designing the data collection instrument, we conducted detailed case studies to discern the types of knowledge pathways that firms utilized and modeled our questions around these responses (Feldman and Kelley, forthcoming). The survey asked the Principal Investigators about their R&D connections to other organizations through a series of questions (Appendix Table A and B). *University Linkages* included resources for technical assistance, and providers of research subsidies and equipment. We also asked about intellectual property licenses with universities and whether a university was the place of prior employment of the project's Principal Investigator. *Business Linkages* includes connections to other firms as customers, and suppliers, research funding sources, and sources of technical assistance, equipment and information. We used a simple count of the presence of these connections to construct an additive measure of the potential pathways through which knowledge might spill-over. We made the simple conjecture that the greater the number of pathways the stronger the potential for knowledge spillovers.

To assess *Willingness to Share Research Results* with other firms, we asked three questions that reflect a tendency towards openness, reflecting the norms of open science (Appendix Table C). The variable is binary and a value of one indicates willingness to share the knowledge created through the R&D project. To demonstrate a willingness to share research results, two of the three statements reflecting openness had to apply. We would expect that, *ceteras paribus*, the government program would subsidize projects that demonstrated openness to sharing results that would be conducive to knowledge spillovers and thus raise the social rate of return to the project.

R&D Project Awards and Knowledge Spillovers: Empirical Results

To estimate the effect of project characteristics in promoting knowledge spillovers on the probability of receiving an R&D subsidy, we use a multivariate logistic regression with maximum likelihood estimation. The dependent variable is program status, which is a binary variable, equal to one if the firm received funding and equal to zero if the firm did not succeed.

The regression results are in Table 2. Model 1 is a basic model that includes project attributes and spillover mechanisms. Models 2 and 3 add controls to this basic specification.

Our findings are robust across the three specifications and indicate that the government program subsidizes projects with the best potential for high social rates of return.

The coefficients on *New R&D Partnership* and *New R&D Direction* suggest that projects that establish a new R&D partnership or exploit a new technical area are more likely to receive the government subsidy, *ceteras paribus*. In both cases, the coefficient is positive and statistically significant at the 5 percent level. Companies with projects involving the formation of new partnerships and or new areas of research for the firm were more likely to receive the R&D subsidy. Projects that involve the formation of new partnerships and explore topics that extend the firms' competencies are likely to be more basic in nature and, thus, would generate greater knowledge spillovers.

Business Linkages is of the expected sign and statistically significant, indicating that firms with greater potential to disseminate R&D results more broadly are more likely to receive the subsidies. *University Linkages* is the only variable that is not of the expected sign and the coefficient is not statistically different from zero. This suggests that firms that received the subsidy did not differ significantly from the firms that did not receive the award, with regard to university linkages. As demonstrated in Table 1, both categories of firms had similar connections to universities (mean of 2.22 and 1.95 with roughly equal variance).

Willingness to share research results is positive and statistically significant and confirms the expectation that the government program would subsidize projects that demonstrated openness to sharing results that would be conducive to knowledge spillovers and thus raise the social rate of return on the project.

Table 2: Logistic Regression Results on Receiving a Government R&D Subsidy

Variable Name	Model (1)	Model (2)	Model (3)
New R&D Partnership	0.556**	0.710**	0.918**
	(0.214)	(0.256)	(0.300)
New R&D Direction	1.690**	1.713**	1.450**
	(0.237)	(0.268)	(0.313)
University Linkages	-0.057	-0.059	-0.091
	(0.081)	(0.090)	(0.110)
Business Linkages	0.142**	0.125**	0.164**
	(0.034)	(0.037)	(0.046)
Willingness to Share Research	0.648**	0.931**	0.834**
Results	(0.246)	(0.283)	(0.317)
First-Time Application		0.075	0.244
		(0.266)	(0.310)
No. of Previous Awards		0.062	0.025
		(0.078)	(0.085)
Proposal Effort ($'s)		0.003	0.003
		(0.018)	(0.002)
Advanced Materials		0.707	1.329
		(0.612)	(0.729)
Biotech		1.271*	2.005*
		(0.854)	(0.804)
Electronics		1.425**	2.008*
		(0.619)	(0.760)
Manufacturing		-0.135	-0.084
		(0.879)	(1.026)
Quality Rating of Technical Plan			0.953**
			(0.176)
Quality Rating of Business Plan			0.584**
			(0.130)
Constant	-2.335**	-3.415**	-17.131**
	(.4601)	(0.836)	(2.370)
Chi-Square	84.89	96.234	195.363
	(df = 5)	(df=12)	(df=14)
-2 Log Likelihood	530.447	449.316	345.910
N	240	240	240

** Indicates statistically significant at 0.025 level (2-tailed test); * Indicates statistically significant at .05 level (2-tailed test).

The results are robust after controlling for other factors that may influence a firm's chances of winning a government subsidy (Model 2). Firms may derive an advantage from having previously applied to the program. To the extent that prior experience with the government agency reflects learning about the proposal selection, the firm's likelihood of receiving a subsidy may increase. Program records were used to assign applicants to the binary category of *First-Time Application.* In addition, *Number of Previous Awards* controls for the extent that prior success may influence the outcome. This variable provides a proxy for agency capture behavior. A positive coefficient on this variable would indicate that firms that had previously received subsidies would have established relationships with the program and be more likely to receive a new subsidy, *ceteras paribus.* Neither of these variables was statistically significant. Prior experience with the program does not appear to affect the subsidy outcome.

We also include a control variable for grantsmanship to differentiate quality of presentation from the quality of the proposed project. *Proposal Effort* reflects the total dollars spent on the application, including the cost of staff time, consulting fees and the cost of materials and travel.[9] We may expect that proposal effort would increase the likelihood of receiving funding. However, the coefficient is not statistically significant indicting that the amount of money spent on preparing the proposal does not affect the likelihood of receiving a subsidy.

Controls are also included for the project's technical area. The omitted category, information technology and software, becomes the baseline for comparison. Controlling for the technology area of the proposed project allows us to assess whether aspects of a firm's R&D strategy merely reflect the prevailing practices in the particular technical area rather than firm strategy. For example, Powell and Doer-Smith (1996) and Zucker, Darby and Brewer (1998) find a high degree of linkages among biotech firms to both universities and to other firms. The results indicate that firms in Biotech and Electronics are more likely to receive an R&D subsidy. Even after controlling for technical area, proposal effort and prior experience with the program, projects that exhibited a greater tendency to generate knowledge spillovers were more likely to receive the subsidy.

Model 3 incorporates the measures of *Technical Quality* and *Business Quality.* All proposals receive independent review by technical specialists on criteria such as quality of the research, technical difficulty and risk, the potential for advancing the state of the art in a specific technical field, and the capabilities of the firm and its R&D partners to carry out the project. In addition, every proposal receives a review by a business specialist that evaluates the technology's commercial viability and potential economic impact. These scores serve as proxies for the overall quality of the proposal. We use the maximum score a project received from any reviewer on a scale ranging from 0 (lowest quality) to 10 (highest quality). The choice of the maximum score was dictated by conversations with program managers about the selection process. A reviewer who assigned a high score to a project is able to see some merit in the research that is not obvious to other reviewers and frequently champions the project through the selection process. Indeed, controversial projects are more likely to represent radical innovation that breaks with existing convention.[10]

Including *Maximum Technical Score* and *Maximum Business Score* allows an assessment of firm R&D strategy separate from general proposal quality in receiving an R&D subsidy. As expected, high technical and business ratings have a positive and statistically significant effect on winning a subsidy. The key finding is that, even after controlling for technical merit and business potential, projects selected for the R&D subsidy are better positioned to deliver public benefits from their R&D activities.

In sum, the results indicate that firms with more extensive linkages to other firms and that exhibit openness in communicating research results were more likely to receive the government subsidy. In addition, projects that opened new research areas for individual firms and that involved establishing new R&D partnerships between organizations were more likely to receive the government subsidy. The coefficient on *Business Linkages* may be used to calculate the marginal effect of an additional link to other businesses on receiving a subsidy. These project characteristics are associated in the literature with greater likelihood to generate knowledge spillovers. Using the result reported in Model 3, one additional link to another firm would increase the probability of receiving a subsidy by 0.25%. Even after we control for a variety of other factors that might affect the application outcome, projects selected for the R&D subsidy are better positioned to deliver public benefits from their R&D activities.

Does Government Funding Makes a Difference?

We contacted the principal investigator one year after the R&D competition and asked about the status of the R&D project. We also asked if the firm had applied to other funding sources for the R&D project and inquired about the dollar amount of any award they had received.

Table 3: Status of Projects Not Subsidized, One Year Later (n=168)

Did not proceed with the project, at any scale	63%	
Proceeded with the projects	37%	
Began project on a much smaller scale than proposed to ATP		17%
Began project on a somewhat smaller scale than proposed to ATP		12%
Began project at about the same scale as proposed to ATP		5%
Began project a somewhat larger scale than proposed to ATP		3%
Began project on a much larger scale than proposed to ATP		1%

If firms pursue the R&D projects in the absence of the government subsidy, we may conclude that the firms were simply substituting government funds for projects that they intended to pursue anyway. Ideally, government investment should induce firms to undertake projects that they would not undertake on their own. At a minimum, we would expect that since firms are required to provide matching funds, they would have some commitment to proceeding with the project. Conversely, the government subsidy may be required to bring the project to within a reasonable internal return hurdle rate.

Table 3 indicates that more than sixty percent of the non-winners have not proceeded with any aspect of the R&D project. This number includes the firms that had gone out of business or firms for which the principal investigator was no longer with the firm. Thirty-eight percent of the non-awardees began work on the proposed project at some level of effort. However, in most instances (76%), the project was pursued at a smaller scale. Only five percent of the firms that did not receive a subsidy proceeded with the project at the same scale. These results suggest that, for the most part, the government program is making a difference in supporting promising R&D projects that, would not otherwise go forward, or would only be pursued by the private sector at a lower scale of effort.

Table 4: Additional Funding Requests and Average Amount Received

	Subsidized Firms	Non-Subsidized Firms	All Applicants
Applied to Other Funding Sources	31	61	92
	(26%)	(50%)	(38%)
Venture Capital	13	21	34
	(43%)	(34%)	(37%)
State Program	12	11	23
	(39%)	(18%)	(25%)
Other Funding Source	18	38	56
	(59%)	(62%)	(63%)
Received Funding	23	14	37
	(73%)	(23%)	(40%)
Mean (St. Dev)	Average Amount Received		
Venture Capital	$3,041,379	$837,719	$1,580,814
	(7,165,867)	(2,861,619)	(4,838,213)
State Program	$465,345	$20,614	$170,581
	(1,849,114)	(70,572)	(1,083,669)
Other Funding Source	$200,517	$13,597	$76,628
	(479,975)	(71,350)	(295,200)
Total Amount	$3,177,931	$900,000	$1,686,428
	(7, 148,416)	(2,906,367)	(4,890,932)

Table 4 presents the number of firms that sought additional funding for the R&D project and the percentages that actually succeeded in attracting funding from these sources in the year after the competition. The period of one year allows us to capture the immediate post-competition response.[11] Overall, ninety-two firms, 38 percent of the applicants applied to other funding sources. Firms receiving an R&D subsidy were less likely to seek additional funding. . However, although only 26 percent of award winners pursued other funding, they were more than twice as likely to raise additional funds than firm not receiving the subsidy (73 percent versus 23 percent).

The sources of funding that the survey asked about were private venture capital, state economic development, public venture capital programs, and other funding sources which included strategic alliances with other companies, or other federal programs such as the SBIR program. The number and percentage of subsidized and non-subsidized firms and their receipt of funding from other sources is reported in Table 4. Companies applied to, and in some cases received money from more than one of these sources. When compared to non-subsidized firms, firms that were awarded the subsidy also received a larger amount from the other funding sources.

There are several explanations why firms that received a government subsidy may have more success at raising subsequent investment. On one hand, firms that receive government subsidies may simply have better R&D projects. Our prior results indicate that while technical quality matters, it is not the only factor determining winning the subsidy. Alternatively, the government R&D award may serve as an information signal to other investors (Lerner 1999; Narayanan *et al*. 2000). Investors prefer projects that are able to demonstrate a high private rate of return. Projects that would yield a high social rate of return would not be of obvious interest to the private investor. However, if a government agency with a reputation for high standards and scientific integrity deems the project investment worthy then other investors may take a closer look. To the extent that the award attracts the attention of other investors and is perceived to certify the potential of the project, subsequent investment in the project may increase. Thus, government funding may confer a "halo effect," and the total amount of R&D investment in firms receiving the R&D subsidy may increase.

To test the effect of receiving a government award on subsequent investment in the project, we estimate two regression models. The dependent variable is the sum of funds that our respondents reported receiving from other sources in the year following their application to the program. Our results are based on a TOBIT regression which accommodates the censored nature of the dependent variable. The amount of additional funding that a firm might receive in the year since the application is truncated at a lower bound of zero. Appendix Table D provides summary statistics for the variables used in these regressions. The ninety-two firms that reported an attempt to pursue additional funding are included in the analysis.

Table 5 presents the results. Model 1 includes the dummy variable, *Awarded Subsidy* to distinguish firms that received the government subsidy award. This is the variable of interest. We add in controls for other factors that may affect the amount of funding that the firm receives. To control for the quality of the R&D project, we include the maximum ratings of *Technical Quality Rating* and *Business Quality Rating.* The previous analyses finds that these ratings are not the only predictors of receiving a subsidy; however, a high score on technical and business quality is an indicator of quality that is expected to attract other investors.[12] The specification includes the log of the amount of *prior R&D funding* the firm received from other sources in the previous two years. We expect that the better the firm's fund raising track record, the greater the amount that the firm is expected to raise for the project in the current period. We include a control for whether or not the firm qualifies as a small business and hence is eligible for funding from sources that target small entrepreneurial firms. The age of the firm is also included as a proxy for the stability of the enterprise and the relative risk of business failure. Even after including these controls, the results suggest that being awarded a subsidy generates a positive and statistically significant effect on receiving additional R&D investment from other sources.

Table 5: TOBIT Regression on the Log Amount of New Funding

	Model 1	Model 2
Awarded Subsidy	3.585*	2.908†
	(1.588)	(1.498)
Technical Quality Rating	-0.114	-0.046
	(0.373)	(0.348)
Business Quality Rating	0.166	-0.117
	(0.418)	(0.399)
Prior R&D Funds Log ($1,000)	0.610**	0.659**
	(0.242)	(0.243)
Age of the Firm	0.083	0.093†
	(0.052)	(0.051)
Small Firm (< 500 employees)	6.020*	5.296†
	(2.900)	(2.815)
Advanced Materials		-2.229
		(2.954)
Biotech		2.483
		(3.312)
Electronics		1.566
		(2.954)
Manufacturing		-3.749
		(3.270)
Constant	-10.035*	-7.625
	(4.545)	(5.077)
-2 Log Likelihood	-154.756	-148.645
χ^2	17.49**	29.71**
Number of Observations	92	92

** statistically significant at probability level ≤ 0.01.; * statistically significant at probability level ≤ 0.05.;
† statistically significant at probability level ≤ 0.10.

Model 2 includes the same set of dummy variables used previously to control for the attractiveness of particular technical areas. The coefficient on the government subsidy decreases slightly but is still statistically significant. Other things being equal, receiving a government subsidy suggests that winning an award triples the amount received from other funding sources. These results suggest that selection for R&D funding by the government program produces information about project quality that is valued by other agents and induces additional investment. Government funding thus creates a halo effect that allows the winning firm to attract subsequent investment. Rather than crowding out other investment, these results suggest that the government subsidy attracts other investment to the project, in effect "crowding-in" other investment.

Conclusion

Jaffe and Lerner (2001: 168) argue that despite their potentially profound impact on growth, government R&D programs have attracted little scrutiny by economists. Much of the conventional wisdom about the incentive effects of government R&D programs and their effect on the behavior of private firms is based on an older generation of R&D programs and subject to confounding effects due to the misaligned incentives created for participating firms (David, Hall and Toole 2000). If firms that received subsidies expected follow-on funding from the government or procurement contracts there would be less incentive to pursue additional R&D investment. A new generation of government R&D programs attempts to address these incentive problems and focus on funding risky projects that provide the potential for economic growth.

The public benefits of such programs are difficult to evaluate due to the circuitous and lengthy path that innovation takes to market (Mansfield et al. 1977). In this paper, we propose criteria to evaluate a project's potential for knowledge spillovers based on an *ex ante* assessment of firm and project characteristics. Funding projects for which the net social benefit is greater than the private return may improve the efficiency of the innovation system and achieve the government program's objective of promoting economic growth.

Many evaluations of public R&D programs suffer from selection bias due to the absence of a control group to provide a counterfactual comparison (Klette, Moen and Griliches, 2000). We address this limitation by collecting data on all firms that applied to a government R&D program. We provide empirical results that find that the program is selecting projects with the potential to generate knowledge spillovers. These results suggest that program managers do examine the broader prospects for the R&D project to generate a high social rate of return rather than simply selecting projects that would have a high profile alone. In addition, program managers do not select projects from firms that had previous contact with the program, all other things equal.

Our results suggest that firms do not pursue R&D projects that did not receive the government subsidy. We also estimate the effect of receiving a government R&D award on the subsequent ability to raise additional money for R&D. Our results suggest that the government subsidy attracts additional investment from other sources for the R&D project. These results stand in stark contrast to the notion that government funding crowds-out private investment. Indeed, these results suggest that government funding certifies the worthiness of an R&D project and provides information that aids others' investment decisions.

The results presented here suggest that government R&D funding complements private R&D. The displacement effect noted by other studies appears to be due to the negative incentives that accompanied those particular R&D subsidies and which are absent in the program evaluated here. Without expectation about further R&D awards and with no possibility for future procurement, government subsidies appear to induce more investment in R&D.

There are several avenues for further investigation. The data that we analyze here is from all firms that applied to one particular program. While this allows a comparison of how firms that receive the subsidy are different from similar firms that did not, there is still selection bias in that we would expect that firms would only apply to this program if they had projects that appeared to satisfy the mandate. That is, the firms that applied to the program are not representative of the larger universe of firms that conduct R&D. Another study should look at firms' decision to apply to the program to see how the projects and firms that apply for government subsidies differ from other firms that conduct R&D. The results presented here are powerful but are based on a small cross-section. We hope that others will follow on with additional research and hopefully richer data to add to the discussion about the incentive effects of government R&D funding for firms and the ultimate effects on innovation and economic growth.

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APPENDIX:

TABLE A: QUESTIONNAIRE ITEMS IN UNIVERSITY LINKAGES INDEX

UNIVERSITY LINKAGES INDEX = $\sum$ Number of Connections

For ATP project and proposal:

1. Did your company first learn about ATP from someone at a university?
2. Did a university help you identify the research partner you consider to be the most important for the project you proposed to ATP?
3. In preparing the technical plan portion of your proposal, did you get assistance from someone at a university?
4. In preparing the business plan portion of your proposal, did you get assistance from someone at a university?
5. [If technical lead on the ATP project has been employed with the company less than 5 years], was this person previously employed at a university?

Other ties to university resources:

6. Does your company have any contracts or licensing agreements for intellectual property at universities?

In the two years prior to your ATP application have you used assistance from a university program

7. to address a technical problem?
8. to prepare a business or marketing plan?
9. to recruit R&D employees?
10. In the two years prior to your ATP application have you formed an alliance with a university to address your needs for equipment and facilities?
11. In the two years prior to your ATP application have any of your R&D personnel attended training or technical programs sponsored by a university?
12. In the two years prior to your ATP application, for your R&D or technology development activities, has your company received funds from a university program?

TABLE B: QUESTIONNAIRE ITEMS IN BUSINESS LINKAGES INDEX

BUSINESS LINKAGES INDEX =∑ Number of Connections

For ATP project and proposal:

1. Did your company first learn about ATP from someone at another company, a consulting firm, or a venture capital firm?

In preparing the technical plan portion of your proposal, did you get assistance from

2. someone at another company?
3. a consulting firm?

In preparing the business plan portion of your proposal, did you get assistance from

4. someone at another company?
5. a consulting firm?

6. [If technical lead on the ATP project has been employed with the company less than 5 years], was this person previously employed at another company?

7. Did someone at a venture capital firm help you identify the research partner you consider to be the most important for the project you proposed to ATP?

8.

ther Business Ties:

In the two years prior to your ATP application have you had assistance in addressing a technical problem from

9. another company?
10. a private consulting firm?
11. a private venture capital firm?

In the two years prior to your ATP application have you had assistance in preparing a business or marketing plan from

12. a private consulting firm?
13. a private venture capital firm?

In the two years prior to your ATP application, has your company received financing for your R&D or technology development activities from

14. another company?
15. a private venture capital fund?
16. an individual (angel) investor?

In the two years prior to your ATP application, to address your needs for equipment and facilities, has your company used

17. an alliance with another company?
18. secured bank financing?
19. private investor or angel financing?
20. venture capital financing?

TABLE C: TENDENCY TOWARDS OPENNESS OR SECRECY

Values of this scale range from 0 to 3,
where 0 indicates a strong tendency towards secrecy and
3 indicates a willingness to share information

To what extent do you intend to make your research results available to other firms and industries?	1= almost always or sometimes; 0= rarely or never
Do you think that keeping your company's R&D knowledge from spreading to other firms is important to your firm's long run success?	1= no; 0= yes
Would you ever consider not engaging in new R&D activity because you believe another firm may benefit from it?	1 = no; 0 = yes

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Table D: TOBIT Regression Descriptive Statistics

	Mean	St. Dev.
Dependent Variable: New Funding Received		
Log ($1,000's)	2.90	3.06
R&D Subsidy Status (Yes = 1; No = 0	0.34	0.48
Log ($1,000's Received in previous 2 years)	4.22	2.94
Age of Firm	10.18	16.00
Small Firm	0.86	0.35
Maximum Reviewer Score on Technical Plan (1, 10)	7.81	2.38
Maximum Reviewer Score on Business Plan (0, 10)	7.49	2.32
Advanced Materials (0, 1)	0.34	0.48
Biotech (0, 1)	0.12	0.32
Electronics (0, 1)	0.41	0.49
Manufacturing (0, 1)	0.13	0.34

[1] The negative effect of government R&D on private R&D expenditures is referred to as crowding-out. Even if there may be less private-sector investment in R&D, the overall level of R&D spending may still increase, unless we assume that for every dollar the government spends on R&D, the private sector spends one less dollar, that is a dollar for dollar decrease. Moreover, the extent of "crowding out" of private sector investment in R&D is related to both the rapidity of the build-up in government R&D funding and the scarcity of skilled labor and capital.

[2] With defense spending there is a tradition of dual use (Alic et al. 1992).

[3] Other Federal R&D programs that provide grants to industry are not exempt from the problems noted with mission agency spending. For example, Wallsten (1998) found evidence of a substitution effect from the Small Business Innovation Research (SBIR) Program which is a fund set aside for small businesses in the mission agency budget. In addition, SBIR has provisions for follow-on funding, in the form of larger, Phase II grants, and allows for unlimited awards to the same companies, although none of these awards are very large. Archibald and Finifter (2000) draw the distinction that some SBIR awardees limit themselves to government service while others use the funds to develop a technology and subsequently move into commercial markets.

[4] There are many attempts to measure the social rates of return yet there are a number of difficult measurement issues (Stephan 1996). However, while economists may argue about the exact magnitude, the consensus is that the social rate of return to R&D is positive and significant and contributes to economic growth.

[5] Katz (1986) predicts that firms may find it in their collective interest to use cooperative R&D agreements to restrict the level of R&D conducted.

[6] For a discussion of the legislation and policy issues that led to the establishment of the ATP, see Hill (1998).

[7] OMB granted approval (no. 0693-0027) for Johns Hopkins University to conduct the survey on March 24, 1999. Copies of the questionnaire are available upon request.

[8] The Schaefer Center for Survey Research at the University of Baltimore conducted the telephone interviews.

[9] From all these sources, the total cost of the ATP application varied considerably, with a median proposal preparation cost of $15,000, and a range from $2,000 to $300,000 per firm.

[10] The results hold when we use mean scores.

[11] Asking this question within one year allows the analysis to hold more factors constant. The longer the time that elapses from the competition to the follow-up the more likely it is that the firm may change its R&D plans or direction. Therefore, the one year time frame permits us to assess the impact of receiving the subsidy at the margin.

[12] The correlation between winning an award and quality rating alone was 0.44 for technical score and 0.39 for business score.