The *ex ante* assessment of knowledge spillovers: Government R&D policy, economic incentives and private firm behavior

Maryann P. Feldman [a,*], Maryellen R. Kelley [b]

[a] *University of Georgia, Institute of Higher Education, 0114 Meigs Hall, Athens, GA 30602, USA*
[b] *Pamet Hill Associates, P.O. Box 636, Truro, MA 02666, USA*

Abstract

This paper investigates the role of government R&D subsidy programs in stimulating knowledge spillovers. R&D subsidies are an effective public policy instrument when knowledge spillovers exist yet *ex ante* it is difficult to identify projects that have the greatest potential to increase innovation and economic growth. This paper derives a set of project and firm attributes that the literature finds generate knowledge spillovers and uses data on project proposals to estimate the degree to which a government R&D program conforms. We find that projects that were awarded R&D subsidies were more likely to have attributes such as participation in new research joint ventures and connections to universities and other firms. Following the post-award activities of firm, we find that receipt of a government R&D subsidy increased the funding from other sources when compared to firms that were not awarded funding.
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1. Introduction

Government R&D programs attempt to encourage innovation and economic growth by supporting projects with the potential to generate high social rates of return. The role of government funding for university research is generally accepted and the subsequent effects on technical progress and economic growth are well-established (Rosenberg and Nelson, 1994). There is controversy, however, when government funds research performed by private companies (David et al., 2000). While industry accounts for approximately two-third of all R&D funding in the US, most of that support is spent on development activity. Market forces provide firms with little incentive to invest in basic research since the non-rival nature of knowledge makes it difficult for firms to appropriate the resulting returns (Nelson, 1959; Arrow, 1962). Firms will not undertake projects if the perception is that knowledge created will be difficult to appropriate.

When the potential for knowledge spillover is high, government subsidies for industry research are an effective public policy tool (Spence, 1984; Trajtenberg, 2001). Rates of return may be calculated once projects are complete; however, funding decisions are made *ex ante*, in advance of information about outcomes. The concern then becomes one of identifying which industry research projects have the greatest potential to generate knowledge spillovers. These are projects that firms would not undertake without the subsidy. While all R&D activity may create spillovers, the management strategy literature offers insights into the extent to which firms have attributes or engage in behaviors that accelerate knowledge flows. If firms with these attributes are awarded R&D funding, then social rates of return will be greater, all other things being equal.

* Corresponding author.
 E-mail address: mfeldman@uga.edu (M.P. Feldman).

This paper makes three contributions to our understanding of government R&D subsidies. First, a set of firm characteristics that the literature suggests would generate knowledge spillovers are developed. Second, these measures are used to empirically test whether a government program has been successful in identifying and awarding research funding to firms that are more likely to generate knowledge spillovers. Awarded firms are compared to a counterfactual group of firms that applied for, but were not granted any funding for their proposed research project. By analyzing all applicants, the problem of selection bias noted with prior studies of R&D subsidies is reduced (Klette et al., 2000). Our results indicate that the government program we examined is selecting projects with greater ability to generate substantial public benefits, even after controlling for technical quality. Third, following firms 1 year after the award decision, we estimate the effect of government funding on the subsequent ability to raise additional money for R&D. Examination of a comparison group demonstrates that firms do not proceed with the projects on their own or significantly scale back their effort in the absence of government funding. This suggests that the award may certify that a project has merit and increase subsequent private investment, conferring a halo on the firm that received the government funding.

The next section of the paper reviews the literature relevant to measuring attributes of firms and projects associated with increased knowledge spillovers. Our empirical focus is on the Advanced Technology Program (ATP) at the National Institute of Standards and Technology (NIST). We introduce the program and discuss our data collection procedures. We then present two sets of empirical models. The first considers the selection criteria. The second considers the subsequent effect of winning an award on the firm's ability to attract additional funding. The final section discusses our findings and their implications for assessing public–private R&D partnerships.

2. Measuring the knowledge spillover potential of R&D projects

While there is significant *ex ante* uncertainty about the social returns from any R&D activity, certain features of industry research projects are associated with a greater likelihood of knowledge spillovers. Cooperative R&D projects are voluntary, reciprocal information-sharing mechanisms that enhance firm learning and subsequent performance (Doz, 1996; Hamel, 1991; Harrigan, 1988; Khanna et al., 1998). When companies work together, the benefits are difficult to confine to a specific project and knowledge will spillover to affect the firm's other activi-

ties. Cooperative R&D projects further enhance welfare effects to the economy by avoiding duplication of effort or inefficient patent races (Reinganum, 1989), and allow firms to leverage differential expertise and make more efficient use of specific assets (Winter, 1987). Studies of the strategies that managers use to learn about other organizations' products, technologies, and business practices emphasize the importance of formal linkages between firms and the informal network ties among engineers, scientists and managers employed in different organizations (Inkpen, 1995; Powell et al., 1996).

In general, this literature indicates that understanding the potential for knowledge spillovers requires examining firms' connections to other organizations. In addition to formal research consortia, firms have other types of less formal 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 et al., 1996). A large number of connections to other organizations indicates that the firm may be an important, central node in the circulation of knowledge throughout a broader network (Granovetter, 1994). While absorptive capacity describes a stock of knowledge, knowledge spillover implies a more dynamic process involving flows of knowledge that may be captured by participation in formal R&D partnerships as well as through supplier–customer relationships, professional associations and mobile human capital. To realize the potential of knowledge spillovers requires connections between organizations. The types of organizations relevant to the formation of such pathways for knowledge spillovers are other firms and universities.

Von Hippel (1988, 1998) demonstrates that downstream users of a technology are a source of knowledge relevant to further R&D and product development. Similarly, Kelley (1993), Sako (1994) and Teece (1992) find that suppliers are more likely to adopt new technologies when their customers provide engineering support. Lim (2004) 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. Limited ties to other organizations may inhibit learning and innovation (Glasmeier, 1991). A greater potential for knowledge spillovers exists when firms involved in R&D projects have multiple supportive connections to other for-profit enterprises.

Universities are an important source of knowledge spillovers given their mission of creating and disseminating knowledge. Gittelman and Kogut (2003) demon-

strate that exchanges between university and industry scientists, as measured by joint publications, have a positive impact on firms' innovative output. Cockburn and Henderson (1998) find that the degree to which pharmaceutical firms are connected to universities and encourage collaboration with academics is important for realizing knowledge spillovers. 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, and hiring students. Each of these mechanisms is a potential conduit for knowledge spillovers. In general, the more linkages that a firm has with universities, the greater the potential for knowledge spillovers and a higher net social benefit for the project.

In addition, basic research projects are expected to yield results that provide 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, 1986). These new research areas would not necessarily be part of the firm's current core competency but might allow the firm to extend its expertise thereby creating new competencies (Bercovitz and Feldman, 2006). Since the intangible results from basic inquiry are more difficult to protect, such research has a higher spillover potential than the more typical applied research and development projects.

In sum, the literature indicates that successful strategies for learning about technical advances outside of a company's internal R&D efforts may depend on the breadth of collaborative links with other enterprises, connections to universities, and the adoption of university norms of publishing research. Most importantly, knowledge flows both ways along these pathways. R&D strategies that open up opportunities for a firm to learn about R&D activities outside its boundaries provide a pathway for multi-directional knowledge flows. Paradoxically, in order to gain direct and early access to the knowledge and technologies being developed in other organizations, a firm has to be willing to share its own accumulated knowledge and technologies with others.

Firms may attempt to keep knowledge within the firm; however, knowledge protection is costly, and at early stages, it is difficult to determine what is valuable and worth protecting (Liebeskind, 1996). Moreover, the value of knowledge may depend on the degree to which that knowledge is communicated to outsiders, and it is only by sharing knowledge that its value may be determined. These uncertainties inhibit the formation of collaborative relationships. Difficulties in establishing and maintaining collaborative ties have been shown to limit the extent and the duration of inter-firm collaborations (Harrigan, 1988). Common interests, complementary expertise and goodwill are important ingredients in establishing and maintaining collaborative arrangements with other organizations (Granovetter, 1994). Moreover, Sako (1992) and Kelley and Cook (1998) have shown that the willingness to volunteer information that benefits the other partner is affected by the institutional context in which firms undertake a collaborative initiative. New collaborative arrangements involve the greatest degree of risk, and encouraging these collaborations requires reducing the costs of collaboration. Hence, government programs that support R&D activities with a high spillover potential provide incentives for firms to engage in behaviors that promote economic growth.

3. Data source and methodology

Our empirical test relies on data about applicants to the 1998 competition of the U.S. Advanced Technology Program at NIST. This program funds early stage industry research projects that have commercial applications and the potential for widespread economic impacts (Jaffe, 1996). The program depends on the initiative of industry to define research projects. The main objective of the ATP is to fund risky (but promising) R&D projects that a firm is not likely to undertake solely with its own resources. However, the program does not expressly favor R&D projects in which participating firms can be expected to have difficulty in appropriating returns for their proposed research efforts. Instead, the program's selection criteria emphasize the importance of a credible commercialization plan and the potential for a profitable return. Moreover, even though the program evaluates each proposal and the capability of the firm to carry out its plans, the program professes to have no preference for certain R&D strategies or practices of the firms it selects for funding. A review panel of independent technical experts and industry specialists evaluates every proposal on its scientific merit and economic potential and these scores were available to us. The program is highly selective and fewer than 20% of proposed projects are awarded funding annually.

To collect data we designed a telephone survey instrument (Feldman and Kelley, 2001). Before the interviews, we followed standard survey method procedures, and sent a letter to explain the purpose of the survey. The letter included a list of questions that the respondent might find helpful to have in advance of the telephone inter-

view. The telephone interview with the project Principal Investigator required 20–30 min to complete. The survey results were matched to independent sources to verify employment, financing and the company founding date. First, we used independent sources such as the CorpTech Database and Hoovers Online Company and Industry Network to verify survey responses concerning employment, financing, and the founding date of the company. Second, 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 prior awards that the firm received. These are used as control variables.

We surveyed 100% of the firms that received a subsidy and a random sample of 50% of the firms that applied to the 1998 ATP competition but did not receive an R&D award. The effective response rate was 60% with 240 completed interviews. We completed interviews with 118 award winners for an 81% response rate (118 completed interviews/147 firms awarded subsidies). For the non-winners, we discovered that within 1 year there were 49 cases that we could not interview, either because the company no longer existed (23 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 (26 cases). We adjusted our response rate accordingly. We completed interviews for 122 non-winners, for a 48% response rate (122 completed interviews/(297 non-subsidized firms − 49 defunct cases)).

Even though the government program does not evaluate a firm's R&D strategy in terms of its connections to other firms, tendency to openness (or secrecy) in communicating its own research findings, whether or not the specific R&D project involves a new partnership with another organization or a technical area/approach new to the firm, these attributes are important to achieving the objectives of the program and to overcoming the difficulties that may be inhibiting technical advance in certain fields.

Descriptive statistics 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 one. 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

Table 1
Descriptive statistics, government subsidy applicants

All firms	Mean	S.D.
Dependent variable: probability of winning an award		
Award status	0.49	0.50
Project characteristics		
New partners	0.41	0.49
New R&D direction	0.33	0.47
Spillover mechanisms		
University Linkages Index	2.08	1.67
Business Linkages Index	4.10	3.49
Willingness to share research results	0.25	0.43
Prior experience with the program		
First application to ATP	0.50	0.50
Number of prior ATP awards	0.56	1.47
Proposal effort (US$)	27,669	35,943
Industry control variables		
Advanced materials (0, 1)	0.33	0.47
Biotech (0, 1)	0.13	0.34
Electronics (0, 1)	0.41	0.49
Manufacturing (0, 1)	0.08	0.27
Controls for project quality		
Maximum technical reviewer score	8.27	1.95
Maximum business reviewer score	7.95	1.98

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, 2002). The survey asked the Principal Investigators about their R&D connections to other organizations through a series of questions (Tables A.1 and A.2). The variable, *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. The variable, *business linkages*, included 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 spillover. 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 academic science (Table A.3). 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, *ceteris paribus*, the government program would subsidize projects of firms that had demonstrated openness to sharing results with other firms. The research projects of such firms would be more conducive to knowledge spillovers and thus raise the social rate of return to the project.

4. 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 LOGIT regression with maximum likelihood estimation. The dependent variable is program award status, which is a binary variable, equal to one if the firm received funding and equal to zero if the firm did not receive funding.

Regression results are presented in Table 2. Model 1 provides a baseline model with project attributes and spillover mechanisms. Models 2 and 3 add controls for other attributes that might be related to winning a government R&D award to the basic specification. The findings

are robust across the three specifications. It appears that the government program selects projects with the highest potential for knowledge spillovers. These are the projects that are most likely to generate high social rates of return.

The positive coefficients on *new R&D partnership* and *new R&D direction* suggest that projects that establish a new research partnership or exploit a new technical area are more likely to receive government funding award, *ceteris paribus*. In both cases, the coefficients are positive as expected and statistically significant at the 0.05 level of probability. We expect that projects that involve the formation of new partnerships and explore new topics that extend the firms' competencies would generate greater knowledge spillovers. These results confirm that the government program is selecting projects that are likely to achieve such spillovers by opening up new pathways for knowledge flows among firms.

The coefficient on *business linkages* is also of the expected positive sign and statistically significant. This indicates that firms with a more diverse set of linkages to other firms are more likely to receive the R&D award. These firms have greater potential to disseminate R&D results more broadly. The greater the type and number of these connections, the greater the potential an R&D project will achieve success in commercialization of technology *and* contribute to the knowledge base of relevant actors in the innovation system. The coefficient on *university linkages* is the only variable that is not of the expected sign and is not statistically different from

Table 2
LOGIT regression results on receiving a government R&D subsidy

Variable name	Model 1	Model 2	Model 3
New R&D partnership	0.556[a] (0.214)	0.710[a] (0.256)	0.918[a] (0.300)
New R&D direction	1.690[a] (0.237)	1.713[a] (0.268)	1.450[a] (0.313)
University linkages	−0.057 (0.081)	−0.059 (0.090)	−0.091 (0.110)
Business linkages	0.142[a] (0.034)	0.125[a] (0.037)	0.164[a] (0.046)
Willingness to share research results	0.648[a] (0.246)	0.931[a] (0.283)	0.834[a] (0.317)
First-time application		0.075 (0.266)	0.244 (0.310)
Number of previous awards		0.062 (0.078)	0.025 (0.085)
Proposal effort (US$)		0.003 (0.018)	0.003 (0.002)
Advanced materials		0.707 (0.612)	1.329 (0.729)
Biotech		1.271[b] (0.854)	2.005[b] (0.804)
Electronics		1.425[b] (0.619)	2.008[b] (0.760)
Manufacturing		−0.135 (0.879)	−0.084 (1.026)
Quality rating of technical plan			0.953[a] (0.176)
Quality rating of business plan			0.584[a] (0.130)
Constant	−2.335 (0.4601)	−3.415 (0.836)	−17.131 (2.370)
Chi-square	84.89 (d.f. = 5)	96.234 (d.f. = 12)	195.363 (d.f. = 14)
−2log likelihood	530.447	449.316	345.910
N	240	240	240

[a] Statistically significant at 0.05 level (one-tailed test).
[b] Statistically significant at 0.05 level (two-tailed test).

zero. This suggests that firms that received the award did not differ significantly from the firms that did not receive the award, with regard to their connections to universities. Both award winners and non-winning applicants had similar connections to universities (mean of 2.22 and 1.95 with roughly equal variance). Although not reported here, there were no statistical differences between winners and non-winners in the component attributes used to measure university linkages. It appears that all of the firms that applied to the government R&D program had strong connections to universities.

The coefficient on *willingness to share research results* is positive and statistically significant. This confirms the expectation that the government program would choose to subsidize projects that demonstrated openness to sharing results. These are the projects that would be conducive to knowledge spillovers and thus raise the social rate of return on the project.

The results are robust after controlling for other factors that may influence a firm's chances of winning a government subsidy (Model 2). The expectation that firms may derive an advantage from having previously applied to the program was not confirmed. We expected that prior experience with the government agency reflects learning about the proposal selection and the firm's likelihood of receiving an award may increase. We used program records to assign applicants to one of two variables that measure prior experience with the program. The variable, *first-time application*, is a binary variable equal to one if the firm had not previously applied to the government program. In addition, the variable *number of previous awards* controls for the number of prior awards that the company received and which may influence the outcome. This variable provides a proxy for agency capture. 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, *ceteris paribus*. Neither of these variables was statistically significant. Prior experience with the program does not appear to affect the award outcome.

We also include a control variable for grantsmanship to differentiate the effort dedicated to the presentation of the proposal from the quality of the proposed project. The variable *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. The total cost of the ATP application varied considerably, with a median proposal preparation cost of US$ 15,000, and a range from US$ 2000 to 300,000 per firm. Because of the extreme differences in the range of spending, the natural logarithm transformation of this variable was used

in the regression model. We would expect that the effort spent preparing the proposal would increase the likelihood of receiving funding; however, the coefficient is not statistically significant. 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 et al. (1996) and Zucker et al. (1998) find a high degree of linkages among biotech firms to both universities and to other firms. 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 the projects' *technical quality* and *business quality*. All proposals receive independent reviews by technical specialists on criteria such as quality of the research, technical difficulty, and technical 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 review by business specialist who evaluates the technology's commercialization potential, the viability of the firm's business plan, and the economic impact that is possible if the firm is successful. These scores, which range from 0 (lowest quality) to 10 (highest quality) serve as proxies for the overall quality of the proposal. We use the maximum score a project received from any reviewer. 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. Including *maximum technical score* and *maximum business score* allow 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 an award. 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 supportive linkages to other firms and those that exhibited 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. Unlike a probit model where the coefficients can be interpreted directly as estimates of the change in probability of an outcome, the coefficients of a logistic regression cannot be interpreted directly as to the magnitude of the effect of a change in a variable on the likelihood function. The entire logistic regression model has to be evaluated in order to estimate the effects of a change in any particular variable. Setting all other variables in the model to their overall means, we evaluated the effect of the coefficient on *business linkages* to estimate the increase in a firm's chances of receiving funding from the program associated with increases in the number of such connections. Considering the range of the index (from 1 to 19 items), we estimated the effects to average 3.4% per connection. Using the results reported in Model 3, a firm with 12 supportive linkages – 3 times the average of 4 financial, technical and other business connections to customers and other types of firms – we estimate the chances of receiving ATP funding to be more than twice (2.2:1) that of the average applicant. Even after we control for a variety of other factors that might affect the application outcome, projects have a much greater chance of selection for the R&D subsidy the more supportive connections they have to other businesses. Because of these connections, such firms are better positioned to deliver public benefits from their R&D activities.

5. Does the type of government funding make a difference?

Ideally, government investment should induce firms to undertake projects that they would not undertake on their own. If firms pursue the R&D projects in the absence of the government subsidy, we could conclude that the firms were simply substituting government funds for projects that they intended to pursue anyway. At a minimum, we would expect that since firms are required to share the costs of the project, non-winners would have some commitment to proceed with the project and might proceed with the research but at a smaller scale.

We contacted the principal investigator 1 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

Table 3
Status of projects not subsidized, 1 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

about the dollar amount of any award they had received. Table 3 indicates that more than 60% of the non-winners have not proceeded with any aspect of the R&D project after 12 months. This number includes the firms that had gone out of business and firms where the principal investigator was no longer employed by the applicant firm. Thirty-seven percent of the non-awardees began work on the proposed project at some level of effort. Only 5% of the firms that did not receive a subsidy proceeded with the project at the same scale. In most instances (76% or 49 of the 62 firms), the project was pursued at a smaller 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 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 longer the time from the competition the more likely that firm may change its R&D plans or direction. The period of 1 year allows us to capture the immediate post-competition response. The one-year time frame permits us to assess the impact of receiving the subsidy at the margin. Overall, 92 firms, or 38% 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% of award winners pursued other funding, they were three times as likely to raise additional funds as those firms that did not receive the subsidy (73% *versus* 23%).

Our survey included a number of questions about the sources of funding. The identified sources included private venture capital, state economic development, public venture capital programs, and other funding sources which included strategic alliances with other companies

Table 4
Additional funding requests and average amount received

	Subsidized firms	Non-subsidized firms	All applicants
Applied to other funding sources	31 (26%)	61 (50%)	92 (38%)
Percentage who applied to other funding sources that applied to			
Venture capital	13 (43%)	21 (34%)	34 (37%)
State program	12 (39%)	11 (18%)	23 (25%)
Other funding source	18 (59%)	38 (62%)	56 (63%)
Received funding	23 (73%)	14 (23%)	37 (40%)
Average amount received, mean (US$)			
Venture capital	3,041,379	837,719	1,580,814
State program	465,345	20,614	170,581
Other funding source	200,517	13,597	76,628
Total amount	3,177,931	900,000	1,686,428

as well as other federal government R&D programs. The number and percentage of subsidized and non-subsidized firms and their receipt of funding from these sources is reported in Table 4. Companies applied to, and in some cases received money from more than one source. When compared to non-subsidized firms, firms that were awarded the subsidy also received a larger amount of funding for their R&D activities from other sources.

There are several explanations for firms that received a government subsidy to have greater 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 was not the only factor in the government's selection of a firm's research project. The announcement of government funding itself may serve as an information signal to other investors (Lerner, 1999; Narayanan et al., 2000), particularly for small firms that would otherwise have difficulty attracting the attention of potential investors. Since private investors prefer projects that are able to demonstrate a high private rate of return, it is not apparent that projects that yield high social rate of return would be of interest. However, under certain circumstances, government funding may confer a "halo" effect on the firm winning an award. Specifically, when a government agency with a reputation for high standards and scientific integrity deems a risky research project to be worthy of a monetary investment, it certifies that the technology has merit. Moreover, when the assessment of the government program is related to the commercialization potential, rather than the government's own use of the technology, then other investors may be more inclined to perceive the award winning project as having greater potential profitability than other

high risk R&D projects. The government subsidy may also bring the project to within a reasonable return hurdle rate for other investors. Thus, government funding may confer a *halo effect*, increasing the total amount of R&D investment in firms receiving the award.

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 all other sources in the year following their application to the program. Our results are based on a TOBIT regression that 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. The use of the log transformation necessitated the specification of the lower bound to be a number greater than zero. Firms that sought funding from other sources but were unsuccessful were coded as having received US$ 1.00 (rather than zero) with a natural logarithm = 0. Table A.4 provides summary statistics for the variables used in these regressions. The 92 firms that reported attempts 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 R&D award from those firms that applied but were not awarded funding. 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 of the *technical quality rating* and *business quality rating*. The previous analyses find 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

Table 5
TOBIT regression on the log amount of new funding

	Model 1	Model 2
Awarded subsidy	3.585[a] (1.588)	2.908[a] (1.498)
Technical quality rating	−0.114 (0.373)	−0.046 (0.348)
Business quality rating	0.166 (0.418)	−0.117 (0.399)
Prior R&D funds log (US$ 1000)	0.610[a] (0.242)	0.659[a] (0.243)
Age of the firm	0.083 (0.052)	0.093 (0.051)
Small firm (<500 employees)	6.020[b] (2.900)	5.296 (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 (4.545)	−7.625 (5.077)
−2log likelihood	−154.756	−148.645
Chi-square	17.49	29.71
Number of observations	92	92

[a] Statistically significant at 0.05 level (one-tailed test).
[b] Statistically significant at 0.05 level (two-tailed test).

attract other investors. The correlation between winning an award and quality rating was 0.44 for technical score and 0.39 for business score, indicating that some high quality projects did not receive an award because they lacked the attributes related to knowledge spillovers. The model specification includes the log of the amount of *prior R&D funding* the firm received from other sources in the previous 2 years—a measure of the firm's past success in raising funds for its R&D activities from sources other than the program in question. We expect that the better the firm's fund-raising track record, the greater the amount 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 would otherwise be eligible for funding from the Small Business Innovation Research program of other federal government R&D agencies and variety of 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 the design of the government program that provides the subsidy matters. Firms that received funding from a government program with a rigorous standard for selection that certifies both the commercial and technical potential of a project attract larger amounts from other R&D funding sources than non-winning firms.

Model 2 includes the same set of dummy variables used previously to control for particular technical areas.

The coefficient on the government subsidy decreases slightly but is still statistically significant. 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.

6. Reflective conclusions

Government funding for university research is uncontroversial, given the existence of market failure; social benefits are substantially greater than private returns due to the existence of externalities or knowledge spillovers. Yet, to realize economic benefits from university research requires private firms to conduct research targeted towards commercialization. A similar market failure exists: the non-rival nature of knowledge makes it difficult to fully appropriate returns from such industry research projects. Yet government funding for R&D conducted by private firms is controversial. A principal–agent problem may exist that would bias the selection of projects towards those with the greatest chances of commercial success rather than those riskier projects that may generate the highest social rates of return. Our analysis suggests that to the extent that the program selection criteria includes an assessment of the spillover potential evident in project and firm characteristics, this problem can be minimized. Another concern is that firms may reduce their own R&D investment when they receive government funding. This suggests that government subsidies may provide a perverse incentive that displaces or crowds-out private investment (see David et al., 2000 for a review). The results presented here suggest that program design may provide incentives for firms to undertake R&D that will have the potential to create positive externalities and increase investment in innovation.

Much of the conventional wisdom about the incentive effects of government R&D programs is based on an older generation of R&D programs and is subject to confounding effects due to the misaligned incentives created for participating firms. David et al. (2000) and Guellec and Van Pottelsberghe de la Potterie (2003) conclude that the substitution effect is due to the predominance of government mission agency spending particularly in the US where this type of program dominates the federal government's R&D funding of business R&D activity

(Kelley, 1997). Mission agencies, such as the Department of Defense, have focused research agenda directed to their specific mandate. Wallsten (1998, 2000) found a substitution effect associated with R&D awards from the Small Business Innovation Research (SBIR) Program, a small business set-aside program for large US mission agencies.

David et al. (2000) suggest 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. Mission agency R&D often relies on long term contracting relationships with follow-on funding or procurement contracts (Cohen and Noll, 1991). Many firms that undertake contract R&D for the government have found a profitable niche with little incentive to venture into commercial markets. When government is the sole customer and is willing to support the R&D necessary to develop that product, there is little incentive for a "captive" supplier to invest in its own R&D. The more dependent the firm on government contracts and the greater the difference between commercial and government technologies, the less likely there will be spillover from government-funded R&D to other sectors of the economy. While some firms still specialize solely in defense contracts, Kelley and Watkins (1995) have shown that many defense contractors make products for commercial (non-government) customers as well. 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. Similarly, Kelley and Cook (1998) show that the technical support and information-sharing norms of the defense contractors' network provide a productivity benefit that is captured in the commercial (non-government) side of their businesses.

The results presented here suggest that the design of government R&D programs is important. Programs that provide subsidies to industry for high risk research with commercial potential provide incentives for firms to undertake R&D that has greater potential for knowledge spillovers and is likely result in an increase investment in R&D activity. The displacement effect noted by other studies appears to be due to the negative incentives that accompanied those particular R&D subsidies. *Ex ante* assessment of firm and project characteristics may be employed by program administrators to evaluate a project's potential for knowledge spillovers and provide criteria for funding projects for which the net social benefit is greater than the private return.

When firms do not receive government funds for this type of research project, our analysis suggests that in most cases, the firms will not continue with the project. We also estimate the effect government funding from this type of program on the subsequent ability of the firm to raise additional money for R&D. Our results suggest that government subsidy for these types of projects will attract 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 that attracts other investors to the firm.

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 et al., 2000). It is possible to address this limitation by collecting data on all firms that applied to a program and making comparisons between winners and non-winners. Such data are consistent with a quasi-experimental program evaluation design, which allows us to empirically test whenther a program is achieving its mandate and to provide information about how program selection criteria might be improved. Moreover, this type of data allows government to examine the broader prospects for their program. 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 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.

Appendix A

Table A.1
Questionnaire items in University Linkages Index

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 2 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 2 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 2 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 2 years prior to your ATP application, for your R&D or technology development activities, has your company received funds from a university program?

University Linkages Index = Σnumber of connections.

Table A.2
Questionnaire items in Business Linkages Index

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?

Table A.2 (*Continued*)

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?

Other business ties

In the 2 years prior to your ATP application have you had assistance in addressing a technical problem from

8. Another company?
9. A private consulting firm?
10. A private venture capital firm?

In the 2 years prior to your ATP application have you had assistance in preparing a business or marketing plan from

11. A private consulting firm?
12. A private venture capital firm?

In the 2 years prior to your ATP application, has your company received financing for your R&D or technology development activities from

13. Another company?
14. A private venture capital fund?
15. An individual (angel) investor?

In the 2 years prior to your ATP application, to address your needs for equipment and facilities, has your company used

16. An alliance with another company?
17. Secured bank financing?
18. Private investor or angel financing?
19. Venture capital financing?

Business Linkages Index = Σnumber of connections.

Table A.3
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

Table A.4
TOBIT regression descriptive statistics

	Mean	S.D.
Dependent variable: new funding received		
Log (US$ 1000's)	2.90	3.06
R&D subsidy status (yes = 1; no = 0)	0.34	0.48
Log (US$ 1000'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

Table A.4 (*Continued*)

	Mean	S.D.
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

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