R&D, Risk, and the Role of Targeted Government R&D Programs

Richard T. Gretz, Joshua J. Lewer, and Robert C. Scott*

ABSTRACT. This paper clarifies the role of passive incentives and targeted government R&D support programs in R&D policy. Using a principal-agent framework, a theoretical model of firm R&D behavior is developed, and suggests that without targeted R&D support programs many R&D projects with the greatest spillover potential would never be undertaken. Passive incentives encourage the firm to conduct a greater amount of R&D, while targeted support encourages the firm to pursue R&D projects it would not normally undertake. These results are independent of the effect of government R&D dollars on private R&D dollars. We incorporate risk into the model to examine programs where targeted funding is reserved for high risk projects. Our theoretical results support current practice of these programs: high risk, high reward R&D projects that would not normally be undertaken by private firms are supported. However, constraining these programs to focus only on high risk projects may cause low risk projects with greater expected benefits to be ignored (O32, D81, H25).

> *[W]hat ethical justification is there for imposing taxes on people to finance scientific research for which they would not voluntarily contribute? ... Given the undisputed success of private financing in the past, the burden of proof that the benefits of government financing exceed the costs surely rest on those who support such financing.*
>
> –Milton Friedman (1981)

I. Introduction

Most industrialized nations encourage greater investment in private research and development (R&D) through the use of passive incentives

*Gretz: Department of Economics, Foster College of Business, Bradley University, 1501 W. Bradley Ave., Peoria, IL 61625; Lewer: Department of Economics, Foster College of Business, Bradley University, 1501 W. Bradley Ave., Peoria, IL 61625, and Research Fellow, Institute for the Study of Labor (IZA), Schaumburg-Lippe-Str. 5-9, D-53113 Bonn, Germany; Scott: Department of Economics, Foster College of Business, Bradley University, 1501 W. Bradley Ave., Peoria, IL 61625. We would like to thank two anonymous referees for perceptive comments. Also, we are deeply indebted to Jannett Highfill for an insightful analysis of an earlier draft. The usual disclaimer applies.

and targeted R&D support. Passive incentives, such as the R&D tax credit, apply to all types of R&D spending while targeted R&D support, such as competitive R&D cost sharing subsidies, are only applicable to specific R&D endeavors. The economic rationale for these policies is that the market will fail to provide an adequate level of R&D because the firm is not able to capture all the benefits to R&D (see Highfill and Scott, 2007; Link, 2006; Tassey, 2005; and Hall, 2002). The question becomes "which policy, passive incentives or targeted R&D support, is better equipped to achieve an efficient allocation of R&D dollars by societal standards?" There is growing support for passive incentives because it is a "market-oriented response as it leaves the choice of how to conduct and pursue R&D programs in the hands of the private sector (Hall and Van Reenen, 2000, p. 449)." The present paper argues that this view may not incorporate all of the goals of R&D policy.

Passive incentives are indeed appropriate when the goal of R&D policy is solely to encourage greater private R&D spending. For example, tax incentives reduce the cost of private R&D and therefore should encourage greater private investment. However, it is possible that the market failure concerns the appropriate R&D project, not whether the right amount of R&D was undertaken. Passive incentives will not encourage the firm to pursue an R&D project with small private benefit over a project with large private benefit. Targeted R&D support may be necessary to encourage the firm to pursue an R&D project with a large relative benefit to society but, absent support, would have small relative benefit to the firm.

It is not surprising that policy makers are leaning increasingly toward passive incentives as the appropriate policy tool rather than targeted R&D support given the econometric evidence. Hall and Van Reenen (2000) review both the U.S. and international data concerning the effectiveness of tax incentives and find a rough estimate of the elasticity of private R&D to tax incentives to be close to unity. Other studies suggest an even greater response by firms. Parisi and Sembenelli (2003) in their panel study of Italian firms find that a 1% increase in tax incentives yields a 1.50% to 1.77% increase in private R&D spending.

While this hardly exhausts the literature concerning the effectiveness of tax incentives and other passive measures, these results have led researchers to question the role of targeted R&D support such as competitive R&D subsidies. In his cross country study of R&D intensity Falk (2006) questions whether targeted subsidies or broad tax incentives is a more effective policy tool for increasing R&D spending. He finds that R&D intensity increases with tax incentives but does not change with subsidy provision. A brief review of other studies confirms Falk's (2006) finding: the evidence for targeted R&D support is mixed (Bloom et al., 2002; Guellec and Van Pottelsberghe, 2003). A meta-analysis done by Garcia-Quevedo (2004, p. 96) finds that "econometric evidence on the relation between public funding of business R&D and private R&D expenditure is ambiguous."

Opponents of targeted R&D support programs have used this evidence to argue for their abolishment. For example, one of the most vocal critics of these programs, the CATO institute, defines such efforts as "corporate welfare." CATO's view is that government dollars substitute for private capital; dollars spent by these government programs are a net loss to society. Slivinski (2007) argues that targeted R&D support goes to large corporations that would otherwise have the means to fund their R&D expenditures.

It is important to note that most studies on the effectiveness of targeted R&D support programs use the same proxy for success as in Slivinski (2007): did the support encourage the firm to spend more R&D dollars? We suggest that this method of evaluating targeted R&D support programs may be flawed. It is not a necessary condition for success that targeted R&D support increase private spending. A function of targeted R&D support may be to encourage the firm to pursue an R&D project most desired by society regardless of whether it increases total private R&D dollars.

To clarify, we define the benefit society receives from a successful R&D project similar to Gretz et al. (2007, 2009): the sum of consumer surplus, producer surplus, and any extra benefits (i.e. spillovers). Theoretical studies of targeted R&D support tend to focus on profit effects only as mentioned by DeCourcy (2005). Wieser (2005), citing the seminal paper by Romer (1990), makes an argument to include 'extra benefits' when modeling R&D policy: "One of the central tenets of *new growth theories* (see Romer, 1990) is, however, that R&D activities not only affect the economic performance of the firms that undertake them but also have repercussions on the performances of other firms. These R&D spillovers or technological externalities arise because of the partially 'public good' nature of knowledge (pp. 587 – 588)."

The formal model in the paper highlights the strategic tension that can exist between policy makers and firms in a simple principal-agent framework. The government chooses a separate passive incentive and targeted R&D support scheme, then the firm chooses to invest in R&D or not. If the firm chooses to invest in R&D then it can choose between investing in a risky project or safe project. The payoff to the government and firm differ by a spillover parameter similar to Gretz et al. (2007, 2009). The assumption is that the firm is not able to capture all benefits which accrue to society.

We find that the government should solely use passive incentives when the spillover benefits of all projects are equal. The government should use targeted R&D support when spillover benefits to risky projects are larger than safe projects. And spillover benefits must be larger as a project becomes riskier in order to justify targeted R&D support.

It should be noted it is not necessary to incorporate risk into the analysis. Indeed, a more basic framework would be to have the firm choose between R&D projects where one project offers greater public benefits than another; the different and necessary functions of both passive incentives and targeted R&D support can be examined as long as the private firm can not capture enough of the benefits of the former project to warrant investment. Passive incentives are used to encourage greater investment in R&D while targeted R&D support programs encourage the firm to pursue a project it would not have undertaken otherwise. In other words, targeted R&D support is necessary to encourage the firm to pursue an R&D project it would not have undertaken even with passive incentives.

We incorporate risk to allow for the situation where proponents suggest targeted R&D support provides the greatest benefit to society: high risk projects with benefits far greater than private profit (Darby et al., 2004). Certain programs have been setup with this in mind. For example the U.S. Advanced Technology Program (ATP) and its successor, the Technology Innovation Program, only consider high risk R&D projects for targeted support. Our results, in large part, support current practice of these programs: high risk, high reward R&D projects that would not normally be undertaken by private firms are supported. However, our results suggest using targeted R&D support on only high risk projects may be problematic. Specifically, low risk R&D projects with large societal benefits but small private benefits are ignored. That is, it is not self evident that the expected value of a high risk project will necessarily yield greater benefits to society than a low risk project. Finally, a simple simulation using spillover estimates from Wieser (2005) suggests projects that receive targeted R&D support have significantly higher spillovers than those that do not. This result complements Feldman and Kelley (2006) who find that, ex-ante, policy makers fund R&D projects with relatively higher spillovers than those that are not funded.

The paper proceeds as follows. The next section derives the theoretical model. The third section simulates the model and discusses some implications. The final section concludes.

II. The R&D Model

We use a simple principal-agent framework to analyze the interaction between the government and a firm choosing to invest in different R&D projects. The government moves first by choosing policy variables. In response, the firm chooses to pursue different types of R&D projects (risky or safe) or not to invest in R&D at all (the game is outlined below). We solve the game using generalized backwards induction and analyze subgame perfect equilibria.

The government's payoff is directly related to the firm's R&D choice, however, the firm's incentives may not be inline with the government's objective function. We assume the government chooses its policy variables to maximize social surplus, as such, we define the payoff the government receives from a particular R&D result as a multiple of the firm's profit. That is, if the firm receives π_i from successfully undertaking R&D project i then the government receives $\gamma_i \pi_i$ where $\gamma_i > 1$ represents the payoff to society including the firm's profit as well as consumer surplus and extra benefits (benefits not captured by the firm or its customers). For example, profit, consumer surplus, and extra benefits from successfully undertaking an R&D project are \$100, \$50, and \$50, respectively. In this case consumer surplus and extra benefits are equal to the firm's profit which implies $\gamma_i = 2$.

Two policy variables are at the government's disposal: a passive incentive (in the amount of p) and targeted R&D support (in the amount of t). The firm receives the passive incentive as long as it engages in any R&D activity while it receives targeted R&D support only if it pursues a specific R&D project (a risky project in this case). Even though the passive incentive and targeted R&D support are treated as transfers to the firm we assume the government incurs administrative costs equal to $c_l(p) > 0$, with $c_l'(p) \geq 0$, for $p > 0$ and $c_h(t) > 0$, with $c_h'(t) \geq 0$, for $t > 0$ when employing the respective policy for each project. This assumption forces the government to minimize its expenditures. Otherwise p and t would have no net effect on the government's payoff function. Further we assume that dollar for dollar it is relatively less costly to administrate and monitor a passive incentive program than administrate, monitor, and identify projects for targeted R&D support, or formally $c_l(x) < c_h(x)$ for $x > 0$ (subscript l implies 'low cost' while subscript h implies 'high cost'). Indeed, this assumption is consistent with arguments for the use of passive incentives over targeted R&D support: one reason why Hall and Van Reenen (2000) argue in support of passive incentives is that it is costly for the policy maker to employ a targeted R&D support program because of the inherent uncertainty in identifying the appropriate technology to promote. For example, ATP evaluates potential projects based on technical merit and commercial feasibility. The selection criteria are rigorous; only about 11% of applications (768 out of 6924 total) received R&D cost sharing awards throughout the life of the program (ATP website). ATP then incurs monitoring and administration costs for those projects which received support.

The game proceeds as follows: the government moves first and chooses p and t. Upon seeing the government's choice of p and t, the firm decides whether to pursue an R&D project or not. The game ends if the firm decides not to pursue an R&D project; the firm and government receive payoffs of π_0 and $\gamma_0\pi_0$ respectively. If the firm decides to pursue an R&D project it chooses between a risky project and a safe project.

For a safe project the firm receives the passive incentive as well as the profit associated with the project, $\pi_s + p$. The government receives their payoff less the administration and monitoring costs of the passive incentive program, $\gamma_s\pi_s - c_l(p)$. The risky project succeeds with probability q and fails with probability $1 - q$. If it succeeds, the firm receives the profit associated with the project as well as the passive incentive and the targeted R&D support, $\pi_r + p + t$. The government receives their payoff less the cost of both programs, $\gamma_r\pi_r - c_l(p) - c_h(t)$. If it fails, the firm has to rely on an old technology but still receives the transfers from the government. The payoff for the firm is $\pi_f + p + t$; the payoff for the government is $\gamma_f\pi_f - c_l(p) - c_h(t)$.

We note two important simplifications in this analysis: (1) the government has perfect information about what type of project a firm pursues and (2) firms do not have to compete for government dollars. The former assumption implies no moral hazard opportunities on the part of the firm (i.e. labeling all projects risky in order to receive targeted R&D support). In practice, the screening processes used by organizations like ATP are quite rigorous, incorporating technology and commercial assessment teams, and can be used to ensure firms do not engage in this type of behavior. The latter assumption is to focus attention on the interaction of the government and firm; not on firm/firm strategy. The interaction between firms competing for scarce government R&D dollars is certainly an interesting study, but beyond the scope of this paper.

To summarize, the extensive form game is presented below (Figure 1) where G represents the government and F represents the firm.

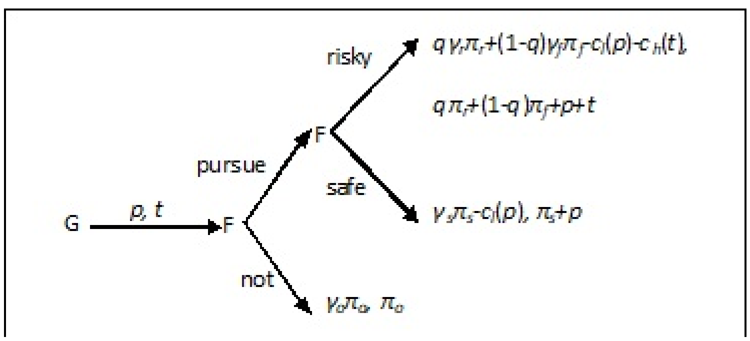

Figure 1. Extensive Form Game

Throughout we assume the following:

$$p \geq 0, t \geq 0 \tag{A1}$$

$$\pi_i > \pi_f \text{ for } i = o, r, s. \tag{A2}$$

$$\gamma_s \pi_s - c_l(\pi_0 - \pi_s) > \gamma_0 \pi_0 \text{ and}$$
$$q\gamma_r \pi_r + (1-q)\gamma_f \pi_f - c_l\left(\pi_0 - (q\pi_r + (1-q)\pi_f)\right) > \gamma_0 \pi_0 \tag{A3}$$

$$\pi_0 > \pi_s \text{ and } \pi_0 > q\pi_r + (1-q)\pi_f \tag{A4}.$$

The first two assumptions are straightforward: assumption (A1) restricts our focus to non negative policy variables and assumption (A2) states the worst outcome for the firm is to pursue a risky R&D project and fail. The last two allow us to focus on interesting cases where the government prefers that the firm pursue an R&D project but the firm prefers not to pursue and R&D project: assumption (A3) states the government's payoff from employing an equilibrium passive incentive strategy which encourages the firm to pursue an R&D project is always preferred to an outcome where the firm pursues no project. (The cost of the passive incentive in the (A3) inequalities, $c_i(\pi_0 - \pi_s)$ and $c_i\left(\pi_0 - (q\pi_r + (1-q)\pi_f)\right)$, are derived below. See equations (4) and (7).) Assumption (A4) states the firm prefers not to perform any R&D in the absence of a passive incentive or targeted R&D support scheme.

Our analysis proceeds as follows, we consider four possible cases absent any passive incentive and targeted R&D support at the project choice decision node: 1) the firm and government prefer the safe project, 2) the firm and government prefer the risky project, 3) the firm prefers the risky project and the government prefers the safe project, and 4) the firm prefers the safe project and the government prefers the risky project. In each of these cases we find the government's equilibrium passive and targeted strategy. Finally, we show how spillovers may influence equilibrium strategies and outcomes.

We assume the firm and government have the same preferences over outcomes in the first two cases. In the last two cases we assume the firm and government differ in their preferences.

A. *Case I: The Firm and Government Prefer the Safe Project*

Absent any passive or targeted support, assume the firm and government prefer that the firm pursue a safe project at the project choice decision node, or formally $\pi_s > q\pi_r + (1-q)\pi_f$ and $\gamma_s\pi_s > q\gamma_r\pi_r + (1-q)\gamma_f\pi_f$. Two constraints must be satisfied for the firm to choose a safe project:

$$\pi_s + p \geq \pi_0 \tag{1}$$

$$\pi_s + p \geq q\pi_r + (1-q)\pi_f + p + t \tag{2}$$

Constraint (1) ensures the firm would choose to participate in pursuing a project while constraint (2) is necessary to guarantee the firm would choose a safe project rather than a risky project. First note that constraint (2) always holds as long as the targeted R&D support is low enough not to encourage the firm to pursue a risky project:

$$0 \le t^I \le \pi_s - q\pi_r - (1-q)\pi_f \tag{3}.$$

Next, because the government's objective function improves as *p* goes down, the government sets *p* so that, in the limit, constraint (1) binds. Solving (1) yields the following equilibrium passive strategy:

$$p^I = \pi_0 - \pi_s \tag{4}.$$

Note that any t^I which satisfies (3) is subgame perfect since the firm's best response is to choose the safe project in the subgame.

B. *Case II: The Firm and Government Prefer the Risky Project*

Formally $q\pi_r + (1-q)\pi_f > \pi_s$ and $q\gamma_r\pi_r + (1-q)\gamma_f\pi_f > \gamma_s\pi_s$. The two constraints which must be satisfied in this case are:

$$q\pi_r + (1-q)\pi_f + p + t \ge \pi_0 \tag{5}$$

$$q\pi_r + (1-q)\pi_f + p + t \ge \pi_s + p \tag{6}.$$

Note inequality (6) holds for $t \ge 0$ given the firm's preference over outcomes. Since we assume dollar for dollar it is relatively costlier for the government to employ a targeted strategy than a passive strategy, the government sets $t^{II} = 0$ and finds p such that (5) binds. Thus from (5), the government's equilibrium strategy for this case is given by

$$p^{II} = \pi_0 - \left(q\pi_r + (1-q)\pi_f\right) \tag{7},$$

and the firm chooses the risky project in equilibrium.

Next we consider two cases where the firm's preferences differ from the government's preferences. We first view the case where the firm prefers the risky outcome and the government prefers the safe outcome.

C. *Case III: The Firm Prefers the Risky Project and the Government Prefers the Safe Project*

The firm's preference and the government's preference over project choice can be formally stated as $q\pi_r + (1-q)\pi_f > \pi_s$ and $\gamma_s\pi_s > q\gamma_r\pi_r + (1-q)\gamma_f\pi_f$, respectively. In other words, the firm has a higher expected value for investing in the risky project compared to the safe project, but after incorporating spillovers into the expected value calculation, the government prefers the safe project. This result may seem counter intuitive if spillovers for risky projects dominate (the implicit assumption of organizations like ATP). However, this outcome can occur even if spillovers for a safe project are smaller than spillovers for a risky project.

For example, assume the firm chooses between investing in a safe project worth \$54 for certain and a risky project with a 50% chance of success. The firm earns \$100 if successful and \$10 if not. (It is worth noting here that a variety of failed projects provide significant profits and economics spillovers, documented specifically in the pharmaceutical market (e.g. Sildenafil/Viagra), for more see Furman et al. (2006)). Notice the firm would choose the risky project since it has a higher expected value (\$55 = \$100 * 0.5 + \$10 * 0.5). Now incorporate the spillover parameters to examine the government's preferences over outcomes. Assume the spillover for the risky project is 2.0, the spillover for the safe project is 1.95, and the spillover for failure is 1.0. The government's expected value if the firm pursues the risky project is \$105 (= 2.0 * 0.5 * \$100 + 1.0 * 0.5 * \$10) while the government's expected value for the safe project is \$105.30 (= 1.95 * \$54); the government prefers the safe project.

In cases like this, the government would rather the firm pursue a safe project. In order for the government to influence the firm to pursue a safe project the following two constraints must be satisfied:

$$\pi_s + p \geq \pi_0 \tag{8}$$

$$\pi_s + p \geq q\pi_r + (1-q)\pi_f + p + t \tag{9}$$

Note that inequality (9) can never hold given the assumption of non negative policies (A1) and the firm's preferences over project choice. Therefore the government can not induce the firm to pursue the safe project. The firm will always choose the risky project for any *p* large enough to encourage the firm to pursue R&D. The government's choice is between the risky R&D project and no project.

The firm will choose the risky R&D project as long as inequality (5) is satisfied. If the government prefers to induce the firm to pursue a risky R&D project it will choose *p* and *t* such that (5) binds. Following the reasoning used when analyzing *Case II* above and noting from assumption (A3) that the government always prefers the firm pursue an R&D project in equilibrium, the equilibrium strategy for the government is given by

$$p^{III} = \pi_0 - \left(q\pi_r + (1-q)\pi_f\right) \text{ and } t^{III} = 0 \qquad (10)$$

and the firm chooses the risky project in equilibrium.

Now we look at the case where the firm prefers the safe project and the government prefers the risky project.

D. *Case IV: The Firm Prefers the Safe Project and the Government Prefers the Risky Project*

Preferences over projects are formally stated as $\pi_s > q\pi_r + (1-q)\pi_f$ and $q\gamma_r\pi_r + (1-q)\gamma_f\pi_f > \gamma_s\pi_s$ for the firm and government, respectively. The government can induce the firm to pursue a risky R&D project if the following two constraints are satisfied:

$$q\pi_r + (1-q)\pi_f + p + t \geq \pi_0 \qquad (11)$$

$$q\pi_r + (1-q)\pi_f + p + t \geq \pi_s + p \qquad (12).$$

Constraint (11) ensures the firm participates in pursuing a project while constraint (12), the effort constraint, guarantees the firm chooses a risky project rather than a safe project. The government will choose *p* and *t* so that (11) and (12) bind in equilibrium. Set the right hand side of (11) and (12) equal to each other when they bind in order to solve for the equilibrium passive incentive:

$$p^{IV} = \pi_0 - \pi_s \qquad (13).$$

Find the equilibrium targeted R&D support by substituting p^{IV} into (12) when it binds and solve for the equilibrium targeted R&D support:

$$t^{IV} = \pi_s - q\pi_r - (1-q)\pi_f \qquad (14).$$

The government will employ the equilibrium targeted R&D support strategy as long as the expected payoff the government receives from the risky project less the cost of the targeted R&D support is greater than the payoff of the safe project: $q\gamma_r\pi_r + (1-q)\gamma_f\pi_f - c_h(t^{IV}) \geq \gamma_s\pi_s$.

Analysis of the four cases above shows that targeted R&D support is accepted by the firm only when the government prefers the risky R&D project in equilibrium and the firm would pursue a safe R&D project absent the support. That is, the government will only give the firm targeted R&D support when their incentives differ in a particular way: the government prefers the risky project and the firm prefers the safe project. Spillovers are crucial in determining whether or not the government's incentives are in line with the firm. In the next subsection we examine how spillovers determine the targeted R&D support strategy for the government.

E. *Spillovers*

Throughout we assume $\gamma_r \geq \gamma_s \geq \gamma_f \geq 1$ which has the following three implications: (*i*) spillovers are non negative, (*ii*) spillovers from the risky R&D project weakly dominate all other spillovers and (*iii*) pursuing a risky R&D project and failing has the lowest spillover benefits. With respect to (*ii*), we make this assumption to be comparable to ATP policy.

First, we find the equilibrium strategy when spillovers are equal, then we examine the case where spillovers to the risky project strictly dominates the others. Interesting implications arise when spillovers are equal. They are summarized in the propositions below. Proposition 1 lays the groundwork for the important implication found in proposition 2.

Proposition 1. When spillovers are equal, $\gamma_r = \gamma_s = \gamma_f = \gamma$ *, the* *government and the firm have the same preferences over project choice absent any passive incentive or targeted R&D support.*

Proof: Assume the government prefers the safe project absent any passive or targeted support, $\gamma_s \pi_s > q\gamma_r \pi_r + (1-q)\gamma_f \pi_f$. Setting the spillovers equal to each other the government's inequality becomes $\gamma \pi_s > q\gamma \pi_r + (1-q)\gamma \pi_f$ or $\pi_s > q\pi_r + (1-q)\pi_f$ which implies the firm prefers the safe project.

Assume the government prefers the risky project absent any passive or targeted support, $q\gamma_r \pi_r + (1-q)\gamma_f \pi_f > \gamma_s \pi_s$. Using the same simplification in the above paragraph the government's inequality becomes $q\pi_r + (1-q)\pi_f > \pi_s$ which implies the firm prefers the safe project.

Finally, assume the government is indifferent between the safe project and the risky project absent any passive or targeted support, $\gamma_s \pi_s = q\gamma_r \pi_r + (1-q)\gamma_f \pi_f$. With equal spillovers the government's equality simplifies to $\pi_s = q\pi_r + (1-q)\pi_f$ which implies the firm is indifferent between the risky and safe project. Q.E.D.

Proposition 2. When spillovers are equal,, the government never provides targeted R&D support to the firm in equilibrium.

Proof: This follows directly from proposition 1 and the analysis of the four cases above. By proposition 1, the government and firm have the same preference over equilibrium outcomes when spillovers are equal. The analysis of the cases shows the government only provides targeted R&D support to the firm in equilibrium when the government prefers the risky project and the firm prefers the safe project. Therefore, the government never provides targeted R&D support to the firm when spillovers are equal. Q.E.D.

Proposition 2 highlights an important implication for policy makers: the government should not try to influence the firm's R&D project decision with targeted support if the spillovers associated with different projects are equal. However, a different strategy may be required when spillovers differ.

Assume that spillovers from the risky R&D project strictly dominate all others. Here we consider the situation where proponents suggest targeted R&D support will provide the greatest benefit to society: risky projects with payoffs far greater than private profit (Darby et al., 2004). We focus on the interesting case where the government would rather the firm pursue the risky project in equilibrium but the firm favors the safe project absent targeted R&D support. It has to be the case that

$$q\gamma_r\pi_r + (1-q)\gamma_f\pi_f - c_l(p^{II}) - c_h(t^{II}) \geq \gamma_s\pi_s - c_l(p^{II})$$

or (simplifying)

$$q\gamma_r\pi_r + (1-q)\gamma_f\pi_f - \gamma_s\pi_s - c_h(t^{II}) \geq 0 \tag{15}$$

in order for the government to weakly prefer the risky project. We rearrange condition (15) to find a range for risky project spillovers necessary to satisfy the government's constraint:

$$\gamma_r \geq \frac{\gamma_s\pi_s - (1-q)\gamma_f\pi_f + c_h(t^{II})}{q\pi_r} \qquad (16).$$

The numerator on the right hand side of (16) can be thought of as the opportunity cost of failure: the government's payoff on the safe project and the cost of targeted R&D support net the government's expected benefit from risky project failure. Essentially, condition (16) states the government will provide targeted R&D support to the firm if spillovers from risky R&D are larger than the ratio of the opportunity cost of failure to expected payout. This strategy, incorporating both passive incentives and targeted R&D support, encourages R&D and influences its direction.

The minimum risky project spillover necessary for the government to implement this strategy is given by (16) when it binds:

$$\gamma_r^* = \frac{\gamma_s\pi_s - (1-q)\gamma_f\pi_f + c_h(t^{II})}{q\pi_r} \qquad (17).$$

The amount of risk is important in determining the minimum acceptable spillover. Recall assumption (A2), the spillover relationships described at the beginning of this section, and the restriction that $c_h'(t) \geq 0$. Then it is relatively straightforward to show the derivative of (17) with respect to q is negative:

$$\frac{\partial \gamma_r^*}{\partial q} = \frac{\left(\gamma_f \pi_f + c_h'(t^{IV})(-\pi_r + \pi_f)\right) q\pi_r - \pi_r\left(\gamma_s \pi_s + q\gamma_f \pi_f - \gamma_f \pi_f + c_h(t^{IV})\right)}{(q\pi_r)^2} < 0$$
$$= qc_h'(t^{IV})(\pi_f - \pi_r) + \gamma_f \pi_f - \gamma_s \pi_s - c_h(t^{IV}) < 0 .$$

This implies that riskier R&D projects require larger spillovers for the government to provide targeted R&D support in equilibrium.

Another useful measure may be the minimum distance between risky and safe project spillovers such that the government still prefers the risky project; policy makers can use this measure to judge whether spillovers are sufficiently different to warrant targeted support. The government is indifferent between safe and risky projects when equation (15) binds. Solving this for the safe project spillover yields

$$\gamma_s^* = \frac{q\gamma_r \pi_r + (1-q)\gamma_f \pi_f - c_h(t^{IV})}{\pi_s} \qquad (18).$$

Equation (18) can be interpreted as the maximum safe project spillover such that the government still prefers to provide targeted support (i.e. pursue the risky project). In other words, the government will prefer the safe project if the safe project spillover is larger than γ_s^*.

Subtracting (18) from (17) yields the desired result; the minimum distance between safe and risky project spillovers such that the government prefers to employ targeted R&D support:

$$\gamma_r^* - \gamma_s^* = \frac{\gamma_s \pi_s - (1-q)\gamma_f \pi_f + c_h(t^{IV})}{q\pi_r} - \frac{q\gamma_r \pi_r + (1-q)\gamma_f \pi_f - c_h(t^{IV})}{\pi_s}$$

or, rearranging

$$\gamma_r^* - \gamma_s^* = \frac{\gamma_s \pi_s^2 - \gamma_r q^2 \pi_r^2 + \left(c_h(t^{IV}) - (1-q)\gamma_f \pi_f\right)(q\pi_r + \pi_s)}{q\pi_r \pi_s} \qquad (19).$$

While (19) might be cumbersome to interpret, we provide numerical estimates below to guide policy makers.

III. Simulation and Discussion

It is important to determine two things: (1) the extent to which society would find itself in a position where the firm would need targeted R&D support to undertake the project most desired by society and (2) how often the government would rather the firm pursue a safe project but the firm pursues the risky project in equilibrium. Among other things, the goal of this section is to examine the frequency of these occurrences in the model. With respect to the former, it can be argued that targeted R&D programs might not justify themselves if their services are rarely required. With respect to the latter, the key is the government can not use targeted R&D support for safe projects in this model. We view this case as it pertains to government organizations such as ATP which are only allowed to fund high risk projects. We perform a simple Monte Carlo analysis to address these concerns. The parameter sets and simulation assumptions are presented in the Numerical Appendix.

Preliminary simulation analysis suggested that spillovers are important parameters for determining outcomes. We refer to the spillover literature to obtain reasonable estimates. Using meta-analysis Wieser (2005) finds "[t]he spillover benefits observed in industry studies are on average two times higher than the private rates of return, yielding mean social rates of return (i.e., private return plus spillovers) to R&D to the order of 90–100% (p. 614)." As such, we let $\gamma_i \sim U(1,3)$ for $i = f, r, s$ for the Monte Carlo analysis. Table 1 displays the frequency of cases I through IV outcomes.

The Case IV column is broken into two sub-columns: No Targeted R&D and Targeted R&D. The Targeted R&D sub-column indicates instances where case IV holds and the government employs targeted R&D support in equilibrium. The No Targeted R&D sub-column occurs when case IV holds but the cost of targeted R&D support is greater than the benefit society receives if the firm pursued the risky project; in equilibrium the government employs only passive incentives and the firm pursues the safe project.

TABLE 1–Frequency of Outcomes for $\gamma_i \sim U(1,3)$ for $i = f, r, s$.
10,000 observations

Case I: The Firm and Government Both Prefer the Safe Project	Case II: The Firm and Government Both Prefer the Risky Project	Case III: The Firm Prefers the Risky Project and the Government Prefers the Safe Project	Case IV: The Firm Prefers the Safe Project and the Government Prefers the Risky Project

			No Targeted R&D	Targeted R&D
6225 (62.25%)	2209 (22.09%)	572 (5.72%)	45 (0.45%)	949 (9.49%)

(Percent out of 10,000 observations listed in parenthesis)

Table 1 shows the case where targeted R&D support is required occurs 9.49% of the time in the sample. This simple simulation indicates that there would be a potentially large forfeit of societal benefit if targeted R&D programs were not available. Also, the government would rather the firm pursue a safe project but the firm does the opposite in 5.72% of cases. This suggests there may be significant societal losses by constricting policy makers to only use targeted support on high risk projects, even if spillovers for these projects dominate.

Table 2 displays descriptive statistics for selected variables when the Case IV Targeted R&D outcome occurs. Descriptive statistics for all cases are included in the Numerical Appendix. The Minimum Spillover for Risky R&D Necessary for Government to Implement Targeted R&D Support, the Maximum Spillover for Safe R&D Project where the Government Still Prefers to Implement Targeted R&D Support, and the Minimum Distance Between Risky and Safe Spillovers where the Government Prefers to Implement Targeted R&D Support are calculated from (17), (18), and (19), respectively.

Results from Table 2 may guide policy makers when considering what types of projects would warrant targeted R&D support. However, it should be noted from the Numerical Appendix that the probability of risky project success is generally higher when firms receive targeted support than when they do not (except in Case II when the firm and government both prefer the risky project).

TABLE 2–Descriptive Statistic of Parameters and Selected Endogenous Variables for Case IV Targeted R&D Outcome. 812 observations.

	Mean	Standard Deviation	Minimum	Maximum
Parameter				
Spillover for Safe R&D Project	2.061	0.452	1.047	2.985

Spillover for Failed Risky R&D Project	1.740	0.485	1.003	2.976
Spillover for Successful Risky R&D Project	2.668	0.303	1.191	3.000
Probability a Risky R&D Project is Successful	0.717	0.211	0.115	1.000
Variable				
Passive R&D Support	0.057	0.073	0.000	0.390
Targeted R&D Support	0.048	0.054	0.000	0.397
Minimum Spillover for Risky R&D Project Necessary for Government to Implement Targeted R&D Support	2.342	0.404	1.091	2.991
Maximum Spillover for Safe R&E Project where the Government Still Prefers to Implement Targeted R&D Support	2.288	0.409	1.107	2.988
Minimum Distance Between Risky and Safe Spillovers where the Government Prefers to Implement Targeted R&D Support	0.054	0.362	-1.328	1.508

Note the average successful risky R&D project spillover is significantly higher than either the failed risky R&D project spillover or the safe R&D project spillover (the null hypothesis of equal means is rejected with 99% confidence in both instances). Also, the Minimum Spillover for Risky R&D Project Necessary for Government to Implement Targeted R&D Support is higher than 2, the average spillover for the range reported by Wieser (2005). Unfortunately, simulations suggest Minimum Distance Between Risky and Safe Spillovers where the Government Prefers to Implement Targeted R&D may not be informative for policy makers. That is, the average minimum distance is 0.054 which may difficult to measure in practice. The policy implication is clear: those R&D projects with relatively higher spillovers should be candidates for targeted support. And higher spillovers should be the major factor in making funding decisions. In practice, the problem may be in identifying which projects are associated with greater spillovers.

Referring to the problem policy makers' face in selecting projects with the largest gap between private and public benefits, Hall and Van Reenen (2000) argue that "in practice this may be very hard … because of the intrinsic uncertainty of knowledge creation (p. 449)." However, recent studies suggest that policy makers have been able to address this uncertainty. Feldman and Kelley (2006), studying cost sharing awards given by ATP, suggest that policy makers, ex-ante, chose to fund R&D projects with relatively higher spillovers. Further, they also provide a set of project attributes associated with larger spillovers.

IV. Conclusions

The results from our model have implications for policy makers: (1) the government should use passive incentives (such as R&D tax credits) when spillovers are the same for different R&D projects, (2) the government may use targeted R&D support when spillovers are different and the spillover to the risky project dominates, and (3) spillover benefits must be larger as a project becomes riskier in order to justify government provision of targeted R&D support. In practice, it may be difficult to accurately measure spillover benefits; however Feldman and Kelley (2006) provide guidance on which projects are associated with relatively greater spillovers and show, ex-ante, policy makers do, in fact, chose to fund R&D projects with relatively higher spillovers.

Given these results, U.S. targeted R&D support programs should be geared toward projects with large spillovers; and they are. However, our analysis suggests the focus on risky projects may be unwarranted. That is, constraining programs like ATP to only fund risky projects may leave safe projects with greater expected value to society than risky projects on the table. While risk may be a concern, the analysis of cases I through IV suggest these programs should encourage firms to pursue projects with relatively high spillovers they would not normally undertake.

It is not surprising that most of the previous literature evaluating the effectiveness of targeted R&D support of private R&D efforts yield mixed results given the implications of the model. We would argue conclusions may be misleading given the usual left hand side variable: did private spending increase? Another left hand side variable may be more appropriate: does social surplus increase? The simple model put forth here implies that a decrease in private spending does not necessarily decrease social surplus. It may be more appropriate to focus on spillovers and other criteria (such as R&D project selection) rather than evaluating targeted R&D support programs on the efficacy of increasing private spending.

Numerical Appendix

This section presents parameter sets used for the Monte Carlo simulations discussed in the Simulation and Discussion section. Parameters for the simulations were randomly selected from the uniform distribution over the ranges given in Table N.A.1. For each simulation we let $\gamma_0 = 1$ which implies no spillovers for society when the firm does not pursue a research project. Also, we assume $c_l(x) = x^{\kappa_l}$ and $c_h(x) = x^{\kappa_h}$ where $\kappa_i \sim U(1,2)$ for $i = h,l$ and $\kappa_h > \kappa_l$ which ensures the monitoring and administration cost restrictions outlined in The R&D Model section hold. Finally, we constrain each simulation to ensure assumptions (A1) – (A4) hold and $\gamma_r \geq \gamma_s \geq \gamma_f \geq 1$. Descriptive statistics for the 10,000 simulations are displayed in table N.A.2.

TABLE N.A.1.–Ranges for Exogenous Parameters Values Used in Monte Carlo Simulations*

Parameter	Minimum	Maximum
q	0.0	1.0
γ_s	1.0	3.0
γ_f	1.0	3.0
γ_r	1.0	3.0
π_o	0.0	1.0
π_s	0.0	1.0
π_f	0.0	1.0
π_r	0.0	1.0

*All parameters randomly selected using uniform distribution.

TABLE N.A.2.–Descriptive Statistic of Parameters and Selected Endogenous Variables in Monte Carlo Simulations–Entire Sample. 10,000 observations

	Mean	Standard Deviation	Minimum	Maximum
Parameter				
q	0.546	0.281	0.000	1.000
k_l	1.507	0.285	1.000	2.000
k_h	1.754	0.217	1.002	2.000
γ_s	2.543	0.411	1.047	3.000
γ_f	2.056	0.567	1.000	3.000
γ_r	2.775	0.265	1.191	3.000
π_o	0.903	0.121	0.174	1.000
π_s	0.813	0.169	0.108	1.000
π_f	0.627	0.245	0.000	1.000
π_r	0.834	0.147	0.110	1.000
Variable				
Passive R&D Support	0.070	0.078	0.000	0.499
Targeted R&D Support	0.006	0.026	0.000	0.397

TABLE N.A.3. Descriptive Statistic of Parameters and Selected Endogenous Variables in Monte Carlo Simulations–Case I. 6,225 observations

	Mean	Standard Deviation	Minimum	Maximum
Parameter				
q	0.461	0.275	0.000	1.000
k_l	1.511	0.283	1.000	2.000
k_h	1.755	0.216	1.002	2.000
γ_s	2.617	0.355	1.212	3.000
γ_f	2.110	0.565	1.000	3.000
γ_r	2.794	0.253	1.404	3.000
π_o	0.911	0.116	0.174	1.000
π_s	0.847	0.147	0.108	1.000
π_f	0.626	0.239	0.001	1.000
π_r	0.812	0.153	0.110	1.000
Variable				
Passive R&D Support	0.064	0.073	0.000	0.499

TABLE N.A.4.–Descriptive Statistic of Parameters and Selected Endogenous Variables in Monte Carlo Simulations–Case II. 2,209 observations.

	Mean	Standard Deviation	Minimum	Maximum
Parameter				
q	0.735	0.202	0.059	1.000
k_l	1.500	0.289	1.001	2.000
k_h	1.754	0.219	1.019	2.000
γ_s	2.529	0.408	1.200	3.000
γ_f	2.103	0.563	1.001	2.999
γ_r	2.770	0.266	1.391	3.000
π_o	0.874	0.136	0.219	1.000
π_s	0.695	0.182	0.111	1.000
π_f	0.564	0.252	0.000	1.000
π_r	0.866	0.133	0.177	1.000
Variable				
Passive R&D Support	0.091	0.086	0.000	0.452

TABLE N.A.5.–Descriptive Statistic of Parameters and Selected Endogenous Variables in Monte Carlo Simulations–Case III. 572 observations.

	Mean	Standard Deviation	Minimum	Maximum
Parameter				
q	0.451	0.215	0.042	0.963
k_l	1.498	0.288	1.000	2.000
k_h	1.742	0.215	1.026	2.000
γ_s	2.645	0.327	1.287	2.999
γ_f	1.843	0.511	1.002	2.959
γ_r	2.781	0.263	1.425	3.000
π_o	0.891	0.125	0.207	1.000
π_s	0.789	0.170	0.143	1.000
π_f	0.746	0.195	0.116	0.999
π_r	0.900	0.113	0.382	1.000
Variable				
Passive R&D Support	0.083	0.087	0.000	0.436

TABLE N.A.6.–Descriptive Statistic of Parameters and Selected Endogenous Variables in Monte Carlo Simulations–Case IV: No Targeted R&D. 45 observations

	Mean	Standard Deviation	Minimum	Maximum
Parameter				
q	0.690	0.211	0.182	0.996
k_l	1.444	0.274	1.028	1.912
k_h	1.664	0.258	1.122	1.968
γ_s	1.942	0.467	1.215	2.886
γ_f	1.656	0.507	1.012	2.818
γ_r	2.588	0.345	1.759	2.998
π_o	0.921	0.101	0.557	1.000
π_s	0.874	0.117	0.505	0.994
π_f	0.551	0.240	0.041	0.965
π_r	0.795	0.133	0.503	0.988
Variable				
Passive R&D Support	0.048	0.055	0.000	0.204

TABLE N.A.7.–Descriptive Statistic of Parameters and Selected Endogenous variables in Monte Carlo Simulations–Case IV: Targeted R&D. 949 observations.

	Mean	Standard Deviation	Minimum	Maximum
Parameter				
q	0.717	0.211	0.115	1.000
k_l	1.505	0.286	1.000	1.999
k_h	1.755	0.222	1.017	2.000
γ_s	2.061	0.452	1.047	2.985
γ_f	1.740	0.485	1.003	2.976
γ_r	2.668	0.303	1.191	3.000
π_o	0.929	0.102	0.269	1.000
π_s	0.872	0.140	0.258	1.000
π_f	0.716	0.239	0.001	1.000
π_r	0.868	0.129	0.307	1.000
Variable				
Passive R&D Support	0.057	0.073	0.000	0.390
Targeted R&D Support	0.048	0.054	0.000	0.397

References

Bloom, Nick, Rachel Griffith, and John Van Reenen. 2002. "Do R&D Tax Credits Work?: Evidence from a Panel of Countries 1979 – 1997." *Journal of Public Economics*, 85(1), 1 – 31.

Darby, Michael R., Lynne G. Zucker, and Andrew Wang. 2004. "Joint Ventures, Universities, and Success in the Advanced Technology Program." *Contemporary Economic Policy*, 22(2), 145 – 61.

David, Paul A., Bronwyn H. Hall, and Andrew A. Toole. 2000. "Is Public R&D a Complement or Substitute for Private R&D? A Review of the Econometric Evidence." *Research Policy*, 29(4 – 5), 497 – 529.

DeCourcy, Julie. 2005. "Cooperative R&D and Strategic Trade Policy." *Canadian Journal of Economics*, 38(2), 546 – 73.

Falk, Martin. 2006. "What Drives Business Research and Development (R&D) Intensity Across Organisation for Economic Co-operation and Development (OECD) Countries?" *Applied Economics*, 38(5), 533 – 47.

Feldman, Maryann P., and Maryellen R. Kelley. 2006. "The *Ex Ante* Assessment of Knowledge Spillovers: Government R&D Policy, Economic Incentives and Private Firm Behavior." *Research Policy*, 35(10), 1509 – 21.

Friedman, Milton. 1981. "An Open Letter on Grants." *Newsweek*, May 18, 99.

Garcia-Quevedo, José. 2004. "Do Public Subsidies Complement Business R&D? A Meta-Analysis of the Econometric Evidence." *Kyklos*, 57(1), 87 – 102.

Furman, Jeffery L., Margaret K. Kyle, Iain M. Cockburn, and Rebecca Henderson. 2006. "Public & Private Spillovers, Location and the Productivity of Pharmaceutical Research." *NBER Working Paper 12509.*

Gōrg, Holger, and Eric Strobl. 2007. "The Effect of R&D Subsidies on Private R&D." *Economica*, 74(294), 215 – 34.

Gretz, Richard T., Jannett Highfill, and Robert C. Scott. 2007. "R&D Subsidies and Multinational Firm Ownership." *Global Economy Journal*, 7(1), Article 5.

Gretz, Richard T., Jannett Highfill, and Robert C. Scott. 2009. "Strategic Research and Development Policy: Societal Objectives and the Corporate Welfare Argument." *Contemporary Economic Policy*, 27(1), 28 – 45.

Guellec, Dominique and Bruno van Pottelsberghe. 2003. "The Impact of Public R&D Expenditure on Business R&D." *Economics of Innovation and New Technology*, 12(3), 225 – 43.

Hall, Bronwyn H. 2002. "The Financing of Research and Development." *Oxford Review of Economic Policy*, 18(1), 35 – 51.

Hall, Bronwyn H., and John Van Reenen. 2000. "How Effective are Fiscal Incentives for R&D? A Review of the Evidence." *Research Policy*, 29(4 – 5), 449 – 69.

Highfill, Jannett, and Robert C. Scott. 2007. "Subsidizing the R&D Expenditures for a Monopoly Firm: Advice for NIST." *Journal of Economics*, 33(2), 21 – 40.

Link, Albert N. 2006. *Public/Private Partnerships: Innovation* ***Strategies and Policy Alternatives*****. Springer.**

Parisi, Maria L., and Alessandro Sembenelli. 2003. "Is Private R and D Spending Sensitive to its Price? Empirical Evidence on Panel Data for Italy." *Empirica*, 30(4), 357 – 77.

Romer, Paul M. 1990. "Endogenous Technological Change." *Journal of Political*

Economy, 98(5), 71 – 102.

Slivinski, Stephen. 2007. "The Corporate Welfare State: How the Federal Government Subsidizes U.S. Businesses." *CATO Studies, Policy Analysis*, 592, May 14.

Tassey, Gregory. 2005. "Underinvestment in Public Good Technologies." *Journal of Technology Transfer*, 30(1 – 2), 89 – 113.

Wieser, Robert. 2005. "Research and Development Productivity and Spillovers: Empirical Evidence at the Firm Level." *Journal of Economic Surveys*, 19(4), 587 – 621.