Why are governmental R&D and private R&D complements? (research and development).

By: Dennis Leyden and Albert N. Link

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Abstract:
It is well known that governmental R&D and private R&D have complementary relationship. However, no previous study has provided an explanation for why that complementary relationship exists. This paper argues that infratechnology is the critical link between governmental and private R&D and that the observed complementarity is the result of technical complementarity at the production level between funding, infratechnology, and knowledge sharing. A theoretical framework based on this argument is developed and examined empirically for supporting evidence. Evidence of technical complementarity is found as well as evidence that governmental R&D stimulates the sharing of knowledge.

Article:

I. INTRODUCTION

For decades, researchers have investigated the government's general role in stimulating private sector innovation.(1) However, with the productivity-growth slowdown in US industries that began in the mid-1960s and accelerated in the early 1970s, researchers began to focus on the direct impact of governmental actions on private-sector research and development (R&D) asking particularly whether governmental R&D allocations to industry complement or substitute for privately-financed R&D.(2) Using firm- or industrial-level cross-sectional data in a single-equation framework, the empirical evidence does, without exception, support a complementary relationship.(3)

Surprisingly, absent from all previous investigations is a theoretical framework to explain why such a complementary relationship exists. Such a broader understanding of the mechanism through which governmental R&D and private R&D interact is imperative if one is to begin to understand the subtleties of the existing empirical findings and, more importantly, to evaluate fully the returns to direct governmental support of industrial innovation. As evidenced by provisions in the Stevenson-Wydler Act, the Bayh-Dole Act, and the Technology Transfer Act, policy makers are challenging, more than ever, the view that public-domain research provides the greater social benefit. To address fully such an issue, more must be known about the benefits from conventional governmental funding to industry and the ways that governmental R&D and private R&D interact.

This paper argues that infratechnology provides the critical link between governmental R&D allocations and private R&D funding, and that the observed complementarity between these two types of funding is itself the result of technical complementarity at the production level between funding, infratechnology, and knowledge sharing.(4,5) Single-equation analyses performed heretofore have generally ignored the role of infratechnology and knowledge sharing and have thus left the impression that the observed complementarity between governmental R&D and private R&D funding is a predetermined outcome of the R&D process. We argue that the observed complementarity is not predetermined. Rather, it is the result of a complex balancing of forces which find their origins in standard production convexities and the technical complementarity referred to above.

A theoretical formalization of these ideas is presented in Section II where an individual firm, confronted with a government R&D allocation, maximizes profits by choosing both a level of private funding and the degree to which it will share its knowledge with outsiders in a quid pro quo process.(6) While the sharing process may impinge on the firm's competitive position, it nevertheless provides the firm with the potential to increase its infratechnology and thus enhance the entire R&D process.(7)

An empirical investigation follows in Section III. It is based on a unique data set drawn from US industrial R&D laboratories. Our initial descriptive analysis confirms the existence of complementarity between governmental R&D and private R&D.

Further analysis, using regression techniques and based on our theoretical framework, finds evidence consistent with the hypothesis that the complementarity between governmental R&D and private R&D is the result of technical complementarity in production between funding, infratechnology, and knowledge sharing.
Section IV provides a brief summary of results and a discussion of the implications both for policy and for further research.

II. A THEORETICAL FRAMEWORK

The R&D production process

Consider a single firm which engages in private R&D in order to increase its profits, and assume further that this firm receives a governmental R&D allocation in return for engaging in a separate R&D process of interest to the governmental. Private R&D culminates in private technological knowledge used in the production of goods and services sold in private markets. Governmental R&D culminates in governmental technological knowledge used by the government in the production of goods and services desired by the government. The degree to which the output of these two activities are similar will vary with the particular nature of the firm's market interest and the type of goods and services the government requires. It is likely, however, that the output of private R&D and governmental R&D will be neither homogeneous nor fungible. For simplicity, we assumed that the two research processes are distinct, and each has a separate production function. The existence of separate production functions, however, need not imply the absence of links between the two processes. Even if the production functions for private R&D and governmental R&D are separate, it is reasonable to assume that they will share the same infratechnology if conducted within the same firm.

To formalize these ideas, define [beta] to be the relative amount of private technological knowledge produced by the private R&D process, and assume that the production function for [beta] can be written as a positive, strictly-concave function of the funds [F.sub.beta] devoted to that process and of the relative level of infratechnology I available to the firm.(8)

[beta] = [beta]([F.sub.beta], I) (1)

Define [gamma] to be the amount of governmental technological knowledge produced by the governmental R&D process, and assume that the production function for [gamma] can be written as a positive, strictly-concave function of both I and the funds [F.sub.gamma] devoted to the governmental R&D process.

[gamma] = [gamma](F.sub.gamma], I) (2)

Finally, assume that I is a strictly-concave function of the funds, [F.sub.I] devoted to the production of infratechnology, the level of the firm's activity S in sharing intellectual activities (such as conferences and symposia), and the level of R&D activity of the firm's competitors M.

I = I(F.sub.I], S, M) (3)

such that [theta.I]/[theta.F.sub.I>0.

S and M represent in a simple way the importance of spillovers to the R&D process. As has been noted by others,(9) the acquisition of knowledge is not free and typically involves large investments. While knowledge can sometimes be acquired in a one-way transfer, the acquisition of knowledge often involves a quid pro quo process in which the firm must share its knowledge with the outside world if it is to acquire outside knowledge. We assume that the firm's level of infratechnology is a positive function of S for low levels of S, but that it eventually becomes negative beyond some critical level of sharing [S.sub.o].

[Mathematical Expression Omitted]

See Fig. 1 for a graphical illustration of this relationship.

The effect of M on I will depend on whether cooperative sharing arrangements exist. If the firm does not engage in such arrangements, a rise in the R&D activity of the industry will reduce the relative value of the firm's infratechnology as other firms invest more in their own infratechnology. On the other hand, if the firm engages in cooperative sharing arrangements, it may be able to benefit from increased R&D activity elsewhere in the industry and thus mitigate, to some degree, the negative effect of a rise in M noted above. In summary

[Mathematical Expression Omitted]

Assume that the firm contributes a total of P dollars of its own funds, while the government provides the firm with G dollars. Also assume that P can only be used for the production of infratechnology or private technological knowledge and that G can only be used for the production of infratechnology or governmental technological knowledge. Assume, in addition, that the firm assigns a constant and exogenous proportion [chi] of P and G to the production of infratechnology.

[F.sub.iqta] = [chi](P + G) (7)

[F.sub.beta] = (1 - [chi]) (8)

[F.sub.gamma] = (1 - [chi])G (9)

From Equations 7, 8 and 9, the production of [beta] and [gamma] described by Equations 1 and 2 can be rewritten as the following strictly-concave functions.

[beta] = B(P, S, G, M) (10)

[gamma] = I (P, S, G, M) (11)

[beta] and [gamma] are positive functions of P and G. The effect of S will depend on the value of S. If S is below the critical level [S.sub.o], [beta] and [gamma] will be positive functions of S; if S is above [S.sub.o], they will be negative functions of S.

Finally, the effect of M will depend on whether the firm engages in cooperative sharing arrangements. If it does not [beta] and [gamma] will be negative functions of M; if the firm does engage in cooperative sharing arrangements, the negative effect will be mitigated to some degree.

The firm's problem

The firm produces an array of goods and services which are sold in intermediate and final markets. Assume that the associated revenue is a positive, strictly-concave function of the firm's relative private technological knowledge, [beta], which, as noted in Equation 10, embodies the effects of S and M. Increase in [beta] are assumed to increase revenue through its impact on the quality and/or size of the firm's product line.

R = r ([beta]) + G (12)

such that [theta.r]/[theta.beta]>0.

Total costs for the firm are the sum of its R&D budget, P, the cost of engaging in governmental R&D, G, and the cost associated with manufacturing the goods and services it sells in the intermediate and final markets, c([beta]).(10)

C = P + G + c([beta]) (13)

Assume that manufacturing costs fall with increases in [beta] at a diminishing rate.

[Mathematical Expression Omitted]

Profits, the summation of Equations 12 and 13, can then be defined by the following convex function.

[PI] = r([beta]) - P - c([beta]) (16)

See Fig. 2 for an illustration of the pattern of revenues, costs, and profits as [beta] increases. Using Equations 10 and 11, profits can be rewritten as a function of P, S, G, and M as follows.

[PI] = R(P, S, G, M) - P - C(P, S, G, M) (17)

Because M and G are exogenous for the firm, the firm's problem is to maximize Equation 17 over the decision variables P and S. This problem is strictly concave in the decision variables. Hence, the solution to the firm's problem will be unique and characterized by the following two first-order conditions

d[PI]/dP = 0 (18)

d[PI]/dS = 0 (19)

which implicitly define the optimal choices for the firm.

P = P(S, G, M) (20)

S = S(P, G, M) (21)

The firm will never refuse a governmental R&D allocation because the effect of such a contract is to increase, at no net cost, the level of infratechnology and thus profits.

Equilibrium

This paper does not explore the determination of G in detail.(11) However, it seems reasonable to assume that the government's demand for [gamma] is some function of the firm's spending and the firm's sharing efforts. Hence, we define the demand for [gamma] to be the following function.

G = G(P, S) (22)

Assuming a Nash equilibrium, equilibrium can be defined as the three-equation system defined by Equations 20, 21 and 22.

Explaining observed complementarity

As noted in Section I, there is strong empirical evidence of a complementary relationship between private and governmental R&D. The model developed above allows us to trace that complementarity to the presence of technical complementarity in the production of both private technological knowledge and infratechnology.

Two inputs to a production process are technically complementary if a rise in one increases the marginal product of the other. Within the context of the model, technical complementarity will exist in the production of [beta] if the following condition holds.

[Mathematical Expression Omitted]

and will exist in the production of infratechnology if the following conditions hold.

[Mathematical Expression Omitted]

[Mathematical Expression Omitted] if there is no cooperative sharing arrangement (25)

[greater than or less than]0 if there is a cooperative sharing arrangement

If the technical complementarity described above does not exist, the model implies the following first-derivative signs for the firm's optimal choice of P and S (Equation 20 and 21).

[Mathematical Expression Omitted]

[Mathematical Expression Omitted] if there is no cooperative sharing arrangement (28)

[greater than or less than]0 if there is a cooperative sharing arrangement

[Mathematical Expression Omitted]

[Mathematical Expression Omitted] if there no cooperative sharing arrangement (31)

[greater than or less than]0 if there is a cooperative sharing arrangement

The negative inequality noted in condition 26 arises because a rise in S (by increasing B) reduces the marginal profit associated with P. Hence, the firm cut back on P. In essence, S is an alternative input to P in the production process. Similar arguments explain the inequalities noted in 27, 29 and 30. The effect of M noted in 28 and 31 depends on whether the firm engages in a cooperative sharing arrangement. If it does not, then a rise in M creates a negative externality for the firm by reducing the firm's relative infrastructure. Hence, the firm chooses to increases P (or S) to compensate. If there is such an argument, rise in M may also provide a mitigating positive externality. Hence, the combined effect is ambiguous.

The negative signs associated with the derivatives [theta.P/theta.S], [Mathematical Expression Omitted], [MathematicalExpression Omitted], and [Mathematical Expression Omitted] would seem to conflict with the observation of a behavioural complementarity of private and public R&D. If, as we believe, private and public R&D are complementary for a wide variety of firms including those that do not engage in sharing, we would expect at a minimum that [theta.P/theta.G] would be positive.

On the other hand, if technical complementarity is present in the production of private technological knowledge and infratechnology (that is, conditions 23 to 25 hold) then a counteracting increase in the marginal productivity of P (or S) will exist. If the technical complementarity is sufficiently strong, the conditions noted in the inequalities 26 to 31 will reverse sign. Thus, within the context of the theoretical framework developed above, the assumption of technical complementarity would seem necessary to explain the complementarity often observes between private and public R&D.

Though technical complementarity may exist, however, it may be too small to reverse the signs noted in the inequalities 26 to 31. Thus, the signs noted in those same inequalities are consistent both with the hypothesis that there is technical complementarity and with the hypothesis that there is not any technical complementarity. Clearly, then, direct evidence of technical complementarity requires finding signs opposite to those noted in Equations 26 to 31.

III. EMPIRICAL EVIDENCE

Descriptive analysis

Our empirical analysis is based on a 1987 data set of 137 R&D laboratories and is derived from an earlier, survey-based effort designed to quantify R&D activity in US industrial laboratories.(12) Hereafter, this data set are referred to as the survey data. For each R&D laboratory, seven variables based on the theoretical framework were constructed. See Table 1 for summary of the descriptive statistics.

[Tabular Data Omitted]

The three primary variables of concern are private R&D, sharing effort of the laboratory, and government R&D. P represents the laboratory's total private R&D budget. The mean value of self-financed R&D was over $23 million. However, as Table 1 reveals, there is considerable variation in the amount of self-financed R&D. S represents the sharing efforts of each R&D laboratory and was approximated from our date set by the percentage of R&D person-hours devoted to activities having public-good characteristics.

To construct S, we took data from an original survey question in which each laboratory director was asked to quantify the R&D output of the laboratory by distributing the total number of person-hours among each of the following eight activity categories: published articles and books, patents and licences, algorithms and software, internal technical and scientific reports, prototype devices and materials, papers for presentation at external conferences, demonstration of technological devices and other products. S was then defined to be the percentage of each laboratory's time devoted to published articles and books and to papers for presentation at external conferences. These two categories reflect, in our opinion, the output activities that correspond best to the concept of shared technical knowledge.(13) S had a sample mean of 8.96% though values ranged widely from 0% (eight observations) to 35.0%.

G represents the government's total spending to acquire governmental technological knowledge. G is calculated from the survey data to include direct government R&D appropriations, contracts, or grants as well as the value of the scientific and technical equipment and facilities financed directly by government resources. The sample mean was $3.44 million, though again there was considerable variation with values ranging from $0 (ten observations) to $174.0 million.

Correlations between P, S, and G (reported in Table 2) indicate (as expected given previous studies) high correlation (0.926) between P and G for the sample. In all cases these correlation coefficients were significant at standard levels of significance. The presence of positive correlation coefficients provides at least preliminary evidence of the existence of technical complementarity at the production level. Correlations between P and S and between G and S are also positive and generally significant, thus providing further initial evidence of technical complementarity at the production level.(14)

Table 2. Sample correlations between the key variables (level of significance in percentage)

	P	G	S
P	1.0		
G	0.926	1.0	
	(0.0001)		
S	0.220	0.248	1.0
	(0.01)	(0.003)	

Four other variables of interest were also considered. M represents the R&D effort of competitors and was approximated by the 2-digit R&D/sales ratio for the laboratory. For example of 137 laboratories, the mean ratio was 4.3 with values ranging from 0.4 to 8.7. The three remaining variables were dummies taking the value of 0 or 1 and were constructed to mark the presence of important activities for which more detailed data was not available. CR marks the presence of formal inter-laboratory agreements and was intended to proxy for the presence of cooperative sharing arrangements. K marks the presence of basic R&D activity, and BL represents the research focus of the laboratory by noting whether or not the firm engages in substantial biological or chemical research.(15) The inclusion of these last two variables is explained below.

Regression analysis

In order to analyze the data further, we parameterized the theoretical framework summarized in Equation 20, 21 and 22 by the following linear, econometric specification.

P = [n.sub.0] + [n.sub.1]S + [n.sub.2]G + [n.sub.3]M + [n.sub.4]M * CR + [[epsilon].sub.P] (32)

S = [[v.sub.0] + [v.sub.1]P + [v.sub.2]G + [v.sub.3]M + [v.sub.4]M * CR + [v.sub.5]BL + [[epsilon].sub.S] (33)

G = [[phi].sub.0] + [[phi].sub.1]P + [[phi].sub.2]S + [[phi].sub.3]K + [[phi].sub.4]CR + [[epsilon.sub.G] (34)

Error terms were assumed to be normally and independently distributed.

Following the discussion in Section II, the predicted signs for [n.sub.1], [n.sub.2], [v.sub.1], and [v.sub.2] are theoretically ambiguous. However, it was our explanation that some, if not all, of them would take on positive values thus providing direct evidence of the presence of technical complementarity in the production of infractechnology and in the production of private technological knowledge. Following the argument summarized in the condition of Equation 6, we inserted the variable M, a proxy for the R&D effort of competitors, twice: once directly and once with the interaction term CR indicating the presence of a cooperative sharing agreement. The parameters [n.sub.3] and [v.sub.3] thus measure the effect of M on P and S in the absence of a cooperative sharing agreement; [n.sub.4] and [v.sub.4] measure the differential effect of M on P and S as a result of cooperative sharing agreements. Although the signs of these parameters are theoretically ambiguous, our expectation was that [n.sub3] and [v.sub.3] would be negative and that [n.sub.4] and [v.sub.4] would be positive thus providing further evidence of technical complementarity. However, because the variable CR indicates the presence or absence of any type of formal cooperative sharing arrangement with competitors, we had less expectation of finding positive signs for [n.sub.4] and [v.sub.4]. Finally, the variable BL was included in Equation 33 to allow for what we felt were substantial differences in the research culture of biological/chemical R&D versus other industries. Because of our belief that biological/chemical R&D researchers share more than non-biological/chemical R&D (mostly engineering R&D in our sample), our expectation was that [v.sub.5] would be positive.

We did not predict the signs of the parameters [phi.sub.1] and [phi.sub.2] from the theoretical framework. However, because we suspected that governmental allocations may favour organizations whose research enriches more directly the nation's science base, we added the variable K to the specification of Equation 34 with the expectation that its parameter [phi.sub.3] would be positive. Finally, previous work has shown that cooperative sharing arrangements tend to be focussed on technologies that are transferred easily between laboratories or firms and, therefore, might be more likely to receive marginal governmental monies if such funding is done so as to increase overall innovative efficiency. (16) We therefore included CR in Equation 34 with the expectation that [phi.sub.4] would be positively signed.

Equations 32 to 34 were estimated using three-stage least squares (3SLS). (17) The results are reported in Table 3. While caution must be exercised in interpreting our findings owing to the exploratory manner in which we approximated several theoretical concepts, the results are generally consistent with the hypothesis of this paper that technical complementarity is present in the R&D process and underlies the complementarity observed by previous studies. Of the four coefficients for the key variables P, S, and G in Equations 32 and 33, three were positive and significant. The remaining coefficient, though insignificant, was negative.

[TABULAR DATA OMITTED]

The other parameters whose signs were derived from the theoretical framework performed similarly with direct support for the hypothesis of technical complementarity coming in the form of negative coefficients in Equations 32 and 33 and a positive coefficient for the M * CR term in Equation 33. Note, however, that of the four coefficients in Equations 32 and 33 associated with the variable M, only one was significant (at a conventional level) and that was for the one not directly supporting our hypothesis.

Finally, our suspicions that biological/chemical R&D laboratories share more and that governmental R&D levels are positively affected by the presence of basic research and cooperative sharing arrangements were confirmed (with varying degrees of significance) by the positive signs for [V.sub.5, [phi.sub.3], and [phi.sub.4]. These results are interesting because they shed light on the mechanism by which governmental R&D stimulates the private R&D funding decision. As noted in Section I, numerous researchers have reported a positive relationship between governmental R&D and private R&D using single-equation models estimated with cross-firm or cross-industry data. The positive and significant coefficient for G in Equation 32 confirms this finding with our sample of laboratories - governmental R&D directly stimulates private R&D. Moreover, governmental R&D also stimulates sharing which, in turn, stimulates private R&D. Accounting for the various feedback effects which link the P and S equations, we find that a $10 million exogenous increase in governmental R&D would result in a $22.9 million increase in private R&D.(18)

Our results also suggest that governmental R&D affects the composition of an R&D laboratory's output. Greater governmental allocations are associated with a greater sharing of technical knowledge. We would, for example, expect that same $10 million exogenous increase in governmental R&D would stimulate almost a 1% increase in the proportion of time spent on activities associated with publishing and paper presentations. For an average employee who works 2000 hours a year, this would amount to an additional 18 hours of such activity. This finding is not inconsistent with the view that government allocates its R&D resources in such a way as to increase social welfare by increasing knowledge per se.

IV. CONCLUSIONS

The purpose of this paper was to investigate the mechanism by which public and private R&D interact. To that end, a theoretical model of R&D activity was developed using infratechnology as the critical link between the two sources of funding. Observed complementarity between public and private R&D funding was then linked to the existence of technical complementarity in the production of infratechnology and private technological knowledge.

Using data from a unique sample of industrial R&D laboratories, we found strong evidence using both descriptive and regression analysis to support the claim that private and governmental R&D are complementary. In addition, we found evidence that governmental RD stimulates the sharing of knowledge outside the laboratory. Finally, we found direct evidence of technical complementarity in six out of eight critical parameters.

There are, to be sure, a number of problems associated with this study. Most notable was the difficulty in finding data which reflects the theoretical concepts underlying the theoretical model. In particular, our measure of sharing was constructed from data on the time allocation of R&D scientists within their laboratory. Although our definition of sharing does conform to an intuitive notion of information dissemination, it would have been nice to confirm our results with other measures. Unfortunately, there are no other such data. These data restrictions further limited our ability to incorporate more sophisticated treatments of spillovers and dynamic effects.

Nonetheless, we believe this study is valuable for three reasons. First, it provides confirmation using another data set and within a new theoretical context for the existence of complementarity between public and private R&D. Second, it provides a general framework for other researchers to investigate the mechanisms by which governmental R&D affects the private sector, rather than simply to investigate the effects of governmental R&D. Third, it provides evidence that governmental R&D has general value not only as a stimulator of private R&D but as a catalyst for sharing technical knowledge.

(1) For overviews of this literature see Nelson (1982) and Link (1987). (2) See Carmichael (1981), Link (1982, 1987), Levy and Terleckyj (1983), Levin and Reiss (1984, 1987), Mansfield and Switzer (1984), Scott (1984) and Levy (1990). Interestingly, Blank and Stigler 91957) raised the same question nearly 35 years ago. (3) Typical is the estimation of the equation P =g(G,X) where P is the level of the firm's (or industry's) own R&D expenditures, G is the level of governmental financial support for R&D received by the firm (or industry), and X is a vector of other factors such as firm size, industry concentration, and product-line diversity. (4) With any R&D activity, infratechnology is used to facilitate the R&D process. Infratechnology may be embodied in such things as structures used for R&D activities, equipment, or pre-existing knowledge used to understand, characterize, or interpret the R&D process. See Link and Tassey (1987) for a description of the general place of infratechnology in facilitating the R&D process. Somewhat broader than their characterization, we assume that the infratechnology in an industry is not generally available to all firms. Rather, firms must incur costs to acquire infratechnology with such technology embodied either in specific pieces of capital or in particular individuals. (5) Two factors of production are (technically) complementary if a rise in one input increases the marginal product of the other input (Hicks, 1948; Ferguson, 1979). The opposite case (in which a rise in one input decreases the marginal product of the other input) has several labels. Hicks refers to it as a ‘regressive’ situation while Ferguson labels such inputs ‘competitive’ or ‘alternative’. (6) See Link and Tassey (1987) and Link and Bauer (1989) on the issue of knowledge sharing. (7) Although they are beyond the intended scope of this paper, issues of uncertainty and dynamic process are clearly important. Our decision to exclude these issues arises both from limited cross-sectional data and from a belief that the effects of uncertainty can be understood best by first understanding outcomes generated by a deterministic framework. For an example of how uncertainty might be incorporated, see Leyden and Link (1992). (8) Note that the values of [beta] and [IOTA] are relative to the general level of private technological knowledge and infratechnology among the firm's competitors. Thus, for example, an increase in the (absolute) level of private technological knowledge by competitors, ceteris paribus, would result in a smaller [BETA] for the firm. (9) See Cohen and Levinthal (1990). (10) We assume that the firm spends all of the governmental R&D allocation g. Hence the cost of engaging in governmental R&D equals G. (11) The derivation of the government's demand for [gamma] would require an elaborate treatment of the political process under which that demand is revealed. For one such treatment in which government demand is motivated by bureaucratic risk aversion, see Leyden and Link (1992). (12) The original R&D laboratory data base included 574 industrial laboratories, 405 of which were in the manufacturing sector. See Link et al. (1990) for a discussion of how the final sample was selected. For a detailed discussion of the data collection effort itself, see Bozeman and Crow (1988). (13) In an effort to place this measure of sharing within the existing R&D literature, we correlated it with some traditional innovation-related variables. Two external data sources were used.

First, 1985 firm-level data from the Census/NSF Longitudinal R&D Data Base were accessed, the data on the following variables were collected: percent of each firm's total R&D budget allocated to process applied research and development; percent of each firm's self-financed R&D allocated to basic research; percent of each firm's total R&D allocated to projects whose total life in the R&D cycle is more than 5 years; and percent of each firm's total R&D funded by the Department of Defense. Our original sample of 137 laboratories was selected based on our ability to match each laboratory's parent firm with data in the Census/NSF Data Base. Given this data, shared technical knowledge, as we measured S, was found to be unrelated to the product/ process mix of a firm's R&D. As expected, less sharing is found in the more basic research firms (simple correlation coefficient - 0.118, significant at the 0.20 level). Sharing is also found less in firms with a larger percentage of their R&D allocated to long-term projects (simple correlation coefficient-0.136, significant at the 0.15 level). Surprisingly, the correlation coefficient between sharing and the percentage of R&D funds from the

Department of Defense is positive. Perhaps those firms receiving R&D funds from the Department of Defense are obtaining them on a product development contract basis. Thus, the source of funding would not necessarily imply that the research was proprietary. This explanation, however, is conjecture on our part.

We also examined how appropriate the Levin et al. (1985, 1987) data was. We related our measure of sharing, averaged across laboratories at the four-digit SIC level, with a Levin et al. (1985) industry-level appropriability index relating to how appropriate the data was. Across industries, there was no significant relationship between the intensity to which resources are devoted to the sharing of technical knowledge and to the use of strategies to appropriate technical knowledge.

Any effort to introduce into the literature a new innovation-related construct, such as our sharing variable, will face criticism and scrutiny. We realize, too, that a case could be made that all of the output activity categorized above becomes public over time. For example, it is possible, over time, to decode software or to reverse-engineer prototype devices. Nonetheless, the empirical analysis presented below is based on our original definition of sharing as discussed above and is not the result of an hoc search to find those categories that verified our model the best. (14) Correlations across 2-digit industry specifications are available upon request. We also examined descriptively the sharing variable S by industry, field of research and level of governmental R&D. In brief, we found that S was larger in R&D-intensive industries. Interestingly, R&D-intensive industries also receive the larger share of government R&D. A complete disaggregation is available upon request. (15) We defined a laboratory as biological/chemical if it had more than 25% of its scientific and technical personnel in the relevant research area as reported on the survey. Non-biological/chemical laboratories are generally engaged in research in the engineering fields. (16)See Link and Bauer (1989). (17)To determine the statistical merits of using 3SLS rather than 2SLS, we follow Belsley (1988). He suggests (p. 28) that 'it would seem safe to say that 3SLS would possess good small-samples relative efficiency [relative to 2SLS] for values of [lambda.sub.min] and det (R) in the neighbourhood of 0.1 and for values of [kappa](R) above 20-30'. Here, the determinant of the cross-equation correlation matrix, det(R), is 0.1596 and the minimum eigenvalue of R,[lambda.sub.min], is 0.093. kappa(R) is the ratio of the maximum eigenvalue to the minimum eigenvalue of R, and it is 22.410. Thus, following Belsley's guidelines, 3SLS would appear to be relatively more efficient than 2SLS.2SLS results are available upon request. (18)To generate the net effect of an exogenous change in G on P and S, Cramer's Rule and the coefficients in Equations 32 and 33 were used.

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