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The Effects of Mission-Oriented Public R & D Spending on Private Industry

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ABSTRACT

This paper addresses the question of how government mission-oriented R & D spending affects private R & D spending and thereby the total investment in technology. The problem is approached within the context of the capital asset pricing model in which the firm views investment projects in terms of their risk and return characteristics. The firm is assumed to produce jointly an established product and an R & D-intensive product, where the latter generates an additional output of technology, or spillover, that is used as an input into the former. By investing in R & D the firm alters its risk and return characteristics in two ways: through the expected profits from the sale of the R & D-intensive good; and through the expected profits from the spillover. In this model, government mission-oriented R & D contracting affects the firm by enabling it to separate to some extent these two sources of risk and return. The main implication of the analysis is that while some public crowding out of private R & D is likely, this is almost certain to be incomplete. The empirical evidence from the U.S. transport industry supports the model and suggests that each dollar of government funding adds around 92 cents to total R & D spending; crowding out private investment by as little as eight percent.

PRIVATE COMPANIES IN THE United States perform a great deal of publicly funded R & D contract work, notably in connection with defence, space exploration, energy, and health. This work is generally believed to make two contributions to society: a direct effect of providing technology-intensive public goods, and an indirect or spillover effect into the technology content of the private goods produced by the firms which undertake the government contracts. For example, space technology has produced heart pacemakers alongside cryogenic insulation materials, while automatic instrument landing systems benefit holidaymakers as well as Air Force pilots.

This argument that government R & D spending has beneficial effects on the output and quality of private sector goods and services is not without its dissidents. There are two main counterarguments. First, it has not been proved in a rigorous scientific way that the spinoffs observed would not have occurred in the absence of the government spending. Second, it is argued that private and public R & D are substitutes. In the extreme case of perfect substitutability, public R & D could crowd out private R & D on a dollar-for-dollar basis.

Reserve Bank of Australia.

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With the exception of some specific case studies, the tests carried out so far on questions relating to R & D[1] have been largely at an aggregate industry level and have attempted to relate the rate of growth of factor productivity in total output[2] to varying combinations of current and lagged private and public R & D expenditures. The evidence from these studies is conflicting and inconclusive. The main difficulty with this approach is that it assumes R & D expenditure to be consistently successful ex post in a predictable manner. This is not necessarily compatible with the fundamental high-risk nature of R & D investment.

The main objective of this paper is to suggest an alternative framework from within which to examine the effects of public R & D contracting. The framework is the theory of capital asset pricing developed by Sharpe [9] and Lintner [8]. The strategy adopted is to construct a model of a firm which undertakes joint production of a standard product and an R & D-intensive product, where the investment in the latter generates a spillover of technology to the standard product. The analysis focuses on the firm's decision to invest in technology and how this decision is influenced by government R & D contracting. This approach enables us to focus clearly on the issue of substitutability between private and public R & D spending. Further, it enables us to utilize the wealth of cross-section data about individual firms.

The analysis concentrates on the private sector's response to mission-oriented public R & D spending. The main characteristic of mission-oriented or contract spending is its low risk to the firm. The contracts typically consist of an agreement to supply a certain R & D-intensive product to the government at a predetermined price. Since the results reported in this paper are dependent on the low-risk feature of contracting, they should not be regarded as generally applicable to all types of public R & D spending.

Section I presents the theoretical analysis of the firm and its investment decision. Section II tests the implications of the theory on a data set drawn from the U.S. transport industry. Section III provides some concluding comments.

I. Government Contracts and the Decision to Invest in Technology

The analysis in this section can be viewed as an attempt to answer the following question: in an uncertain world with perfectly competitive capital markets, how does public contracting of R & D projects affect the value of the firm and its production of R & D-intensive capital? In the model presented below, the firm is assumed to undertake joint production of a conventional product (for sale in an established market) and an innovative product. The innovative output is R & D-intensive and offers a high expected yield and a high variance relative to the conventional output. An important link in the model is the assumption that investment in the R & D-intensive good generates an output of technology that can be used as an input in the production of the established product. The analysis

[1] See, for example, Griliches [4, and 5], Goldberg [1], and Terleckyj [10].

[2] Since spillovers are argued to affect the private output of the firm, the use of total output biases the results of these tests to an unknown degree. Griliches [5, p. 93] makes the comment that the production function approach is "currently · · · the only available general way of trying to answer questions about the contribution of R & D to growth."

is carried out within the framework of the Sharpe-Lintner capital asset pricing model. A brief review of this framework follows.

A. The Capital Asset Pricing Model

The basic capital asset pricing model uses a one-period decision horizon. At the end of the period, firm i returns to its shareholders a total dollar earning of $\tilde{x}_i$ (dividends plus change in the market value of its equities) with an expected value at the beginning of the period of $\bar{x}_i$ and a variance of σ_i^2. The return of firms i and j have a covariance σ_{ij} and firm i's return has a covariance with the return on the market portfolio of σ_{im}. Individual investors are assumed to maximize a utility function which depends on the mean and standard deviation of their wealth at the end of the single period of analysis.[3] With this assumption, plus certain restrictions on the competitive nature of the market and the availability of information,[4] the value, V_i, of firm i is determined by the relationship:

$$V_i = \frac{1}{r}\left[\bar{x}_i - \lambda_m \sigma_{im}\right] \tag{1}$$

where r is the risk-free rate of return, $\lambda_m = (\bar{x}_m - rV_m)/\sigma_m^2$ is the market price of risk, and a subscript m refers to the market portfolio. That is, the valuation of any given firm is the certainty equivalent of its dollar returns, discounted at the risk-free rate of interest. The only characteristics of the individual firm which influence its value are its expected returns and the covariance of these returns with the market portfolio. The covariance σ_{im} is a measure of the undiversifiable risk of firm i.

Early contributions to the theory were concerned with the determination of market-clearing prices for fixed quantities of assets. Recent contributions[5] have used the model as a framework within which firms make their investment decisions. The firm is viewed as generating expected returns and risk from its potential investments. For a wide class of investment decisions, the output of expected returns can be shown to be concave in risk so that the choice of an optimal level of investment by value maximization is a well-defined problem. This approach will be extended below to the case of joint production to facilitate analysis of investment in R & D.

B. Investment in R & D with Public Contracting

Consider a single firm, i, that produces two goods, A and B. The first product is sold in an established market and offers the firm a total dollar return $\tilde{x}_a$, with expected value $\bar{x}_a$ and variance σ_a^2. The uncertainty can be thought of as relating to unpredictability of final sales or of selling price. The second product is R & D-intensive. The firm will choose an amount $\$k$ to invest in the second product. On private funds it offers a net return of $\tilde{\rho}$ dollars per dollar invested, with expected value $\bar{\rho}$, and variance σ_ρ^2. Note that the return and variance per dollar invested

[3] For a further discussion of this assumption in the literature, see Jensen [6].

[4] The most important restriction is that all investors hold the same subjective probability distributions about expected earnings. For a more comprehensive discussion see Jensen [6].

[5] See, for example, Jensen and Long [7] and Greenberg et al. [3].

are independent of the level of the investment. Jensen and Long [7] have labeled this assumption constant stochastic returns to scale.

In addition to production of the high-technology product, the investment in B is assumed to generate an output of technology that serves as an input to the conventional product A. This spillover is additional to, and distinct from, the marketable product B that results from the investment. The importance of the spillover is reflected in the dollar returns associated with this technological transfer. I will define the return as $\tilde{\theta}f(k, \bar{x}_a)$, where $\tilde{\theta}$ is a random variable with expected value $\bar{\theta}$ (greater than zero) and variance σ_θ^2. Thus, the process of transfer is uncertain and depends on the level of R & D expenditure[6] as well as on the expected return to the standard product.[7] I will assume nonincreasing returns in the technology transfer process, so that: $f_1, f_2 > 0$, $f_{12} = f_{21} > 0$, $f_{11}, f_{22} \leq 0$ and $f(0, \bar{x}_a) = 0$. I will also assume that the outputs A, B, and $f(\cdot)$ are all "normal" in the sense of having a positive covariance with both the market and each other.

Suppose that the government approaches the firm with a mission-oriented R & D contract. Since any R & D effort involves the accumulation of knowledge and technical expertise there is no reason to assume that the spillover from k dollars of public R & D will be greatly different to the spillover from k dollars of private R & D. Where the private and public undertakings differ will be in the risk and return characteristics of the technology-intensive output itself. What I have called a fixed-price contract is where the government contracts for the delivery of a quantity of product B at a fixed price; for example, cost plus a small margin. The government in this case is the final market for B and by accepting the final product at a fixed price it is essentially bearing all the potential risk and returns from the contracted R & D output. The total return to the firm from the government contract is small and known with certainty. I will define the net return to the firm per dollar of government contract to be δ. This return is nonrandom and is usually the subject of negotiation. The total dollar return is δk_g where k_g is the dollar size of the contract. It will be positive or negative as δ is positive or negative.

Given a fixed-price government R & D contract of size k_g, the firm will undertake an additional amount of private R & D, k_p. Define the total R & D project for the firm as $k_t = k_g + k_p$. For arbitrary values of k_p and k_g the total dollar returns to the firm are:

$$\tilde{x}_i = \tilde{x}_a + \tilde{\theta}f(k_t, \bar{x}_a) + \tilde{\rho}k_p + \delta k_g \tag{2}$$

The covariance of these returns with the market portfolio are:[8]

[6] I have associated the spillover with the size of the investment rather than to the outcome of the R & D product. We can think of the R & D process as generating joint outputs of B and technology. The technology is experience or expertise obtained simply by undertaking the research involved in exploratory production. Even if B is a market failure, the firm will have acquired some technical knowledge from the attempt to produce it commercially. The spillover can also be thought of as including expected future profits from securing markets and future contracts.

[7] The relationship of $\bar{x}_a$ to $f(\cdot)$ is that of a scaling factor. If $f(\cdot)$ takes the form of $f(k)\bar{x}_a$ then the technology transfer is worth $f(k)$ per unit of conventional output.

[8] This expression follows from the definition of σ_{im} as $\text{cov}(\tilde{x}_i, m) = \text{cov}(\tilde{x}_a + \tilde{\theta}f(k_t, \bar{x}_a) + \tilde{\rho}k_p, \tilde{x}_1 + \tilde{x}_2 + \cdots \tilde{x}_a + \tilde{\theta}f(k_t, \bar{x}_a) + \tilde{\rho}k_p + \cdots \tilde{x}_n)$, where I have defined σ_{am}, $\sigma_{\theta m}$, and $\sigma_{\rho m}$ as covariances with the initial market portfolio; that is, before any investment in R & D.

$$\sigma_{im} = \sigma_{am} + f(k_t, \bar{x}_a)(\sigma_{\theta m} + \sigma_{\theta a}) + k_p(\sigma_{\rho m} + \sigma_{\rho a}) + 2f(k_t, \bar{x}_a)k_p\sigma_{\theta\rho} + f(k_t, \bar{x}_a)^2\sigma_\theta^2 + k_p^2\sigma_\rho^2 \quad (3)$$

Utilizing (1) we can write the value of the firm with private and public R & D spending as:

$$V_i = \frac{1}{r}\{\bar{x}_a + \bar{\theta}f(k_t, \bar{x}_a) + \bar{\rho}k_p + \delta k_g - \lambda_m[\sigma_{am} + f(k_t, \bar{x}_a)(\sigma_{\theta m} + \sigma_{\theta a}) + k_p(\sigma_{\rho m} + \sigma_{\rho a}) + 2f(k_t, \bar{x}_a)k_p\sigma_{\theta\rho} + f(k_t, \bar{x}_a)^2\sigma_\theta^2 + k_p^2\sigma_\rho^2]\} \quad (4)$$

Following Jensen and Long [7] we can view the decision to invest in R & D in terms of the choice of a value of k_p that maximizes the value of the firm, as expressed in (4). For the optimal value k_p^* to yield a value maximum, it is essential that the objective function $V_i(k_p)$ be concave. In the single-product investment models of Jensen and Long [7] and Greenberg et al. [3], concavity is relatively straightforward. Earnings are typically linear in the investment while covariance with the market portfolio is quadratic. Thus, increases in investment generate positive increments to the firm's market value up to the point at which the quadratic terms begin to dominate.

The earnings term in the current model, $(\bar{x}_a + \bar{\theta}f(\cdot) + \bar{\rho}k_p + \delta k_g)$, is increasing in k_p with a second derivative that is less than or equal to zero as f_{11} is less than or equal to zero. The covariance term, contained in the square brackets of (4), is also increasing[9] in k_p but with a second derivative complicated by the presence of the spillover. This second derivative is: $f_{11}(\cdot)(\sigma_{\theta m} + \sigma_{\theta a}) + 2k_pf_{11}(\cdot)\sigma_{\theta\rho} + 2f(\cdot)f_{11}(\cdot)\sigma_\theta^2 + 2f_1(\cdot)^2\sigma_{\theta\rho} + 2f_1(\cdot)\sigma_{\theta\rho} + 2f_1(\cdot)^2\sigma_\theta^2 + 2\sigma_\rho^2$, where the first three terms are negative when $f_{11}(\cdot) < 0$, and the last four terms are positive. The key to the concavity of $V_i(k_p)$ is the convexity of the covariance term, which in turn requires the above second derivative to be positive. Essentially this requires that the quadratic terms in the valuation equation, $f(\cdot)^2\sigma_\theta^2$ and $k_p^2\sigma_\rho^2$, dominate the lower-order terms. A sufficient condition for this to hold is $f_{11}(\cdot) = 0$. Clearly, the same result can be achieved with a much weaker condition since the second derivative involves several offsetting terms in $f_1(\cdot)$ and $f_{11}(\cdot)$. In general, $V_i(k_p)$ will be concave provided $f_{11}(\cdot)$ is not too large relative to $f_1(\cdot)$. For simplicity I will assume from here on that $f_{11}(\cdot) = 0$, since this condition also ensures the existence and uniqueness of the optimum.[10] It does not, however, ensure a maximum at $k_p > 0$ and this possibility must be allowed for.

For (4) to be a valid representation of the investment decision, I have implicitly assumed that the choice of k_p can be made independent of any decision about the scale of operations involving the standard product. We might think of the decision in the following way. At the beginning of the period (of undefined length), a decision is made about how much to invest in the R & D-intensive good. At the

[9] As in the single good case, negative covariances could lead to a decreasing variance for small values of k_p. However, since these terms are eventually dominated by the variance terms σ_θ^2 and σ_ρ^2, the assumption made above of positive covariances is not unduly restrictive.

[10] Some of the proofs contained in the paper utilize the assumption that $f_{11} = 0$. The proofs rely essentially on the concavity of $V(\cdot)$ and should therefore continue to hold for any set of weaker assumptions, provided that the concavity of $V(\cdot)$ is not violated.

end of the period, if the product is successful, it is absorbed into what I have called the standard product (which could, of course, be several lines of production). Thus, the next period starts with a new set of R & D investment opportunities and a predetermined scale of production for the established good.[11]

Choosing k_p to maximize (4) leads to the following optimality condition:[12]

$$k_p^* = \max\{0, [f_1(k_t^*, \bar{x}_a)(\bar{\theta} - \lambda_m(\sigma_{\theta m} + \sigma_{\theta a} + 2f(k_t^*, \bar{x}_a)\sigma_\theta^2)) + \sigma_{\rho a} + \sigma_{\rho m} + 2f(k_t^*, \bar{x}_a)\sigma_{\theta\rho} + \bar{\rho}]/[2\lambda_m(f_1(k_t^*, \bar{x}_a)\sigma_{\theta\rho} + \sigma_\rho^2)]\} \quad (5)$$

where $k_t^* = k_p^* + k_g$.

The main qualitative implications of public R & D contracting for the firm are contained in the following three propositions:

PROPOSITION 1: *Provided that k_p^* and k_g are positive, complete crowding out will not occur.*

Proof: When $k_p^* > 0$, the second equality in (5) becomes operative. Define the terms in the square brackets as $F(k_t^*)$ and re-arrange the equality as $k_t^* - F(k_t^*) = k_g$ by adding k_g to both sides. For incomplete crowding out to occur it is necessary that k_t^* be greater when $k_g > 0$ than it is when $k_g = 0$. This will be the case, provided $F(k_t) > k_t$ when $k_t < k_t^*$. The proof of the proposition therefore requires a proof that $F'(k_t) < 1$. From the definition of $F(\cdot)$ we get:

$$F'(k_t) = \{\bar{\theta}f_{11}(\cdot) - \lambda_m[f_{11}(\cdot)(\sigma_{\theta m} + \sigma_{\theta a} + 2f(\cdot)\sigma_\theta^2) + 2f_1(\cdot)\sigma_{\theta\rho} + 2(f_1(\cdot))^2\sigma_\theta^2] - 2\lambda_m f_{11}(\cdot)\sigma_{\theta\rho}F(\cdot)\}/2\lambda_m(f_1(\cdot)\sigma_{\theta\rho} + \sigma_\rho^2)$$

From our assumptions that $f_1 > 0$ and $f_{11} = 0$, this reduces to $F'(k_t) = -[f_1(\cdot)\sigma_{\theta\rho} + (f_1(\cdot))^2\sigma_\theta^2]/[f_1(\cdot)\sigma_{\theta\rho} + \sigma_\rho^2]$, which is unambiguously negative.

Since further differentiation of $F(\cdot)$ establishes that $F''(\cdot) = 0$ we get the following result:

COROLLARY: $\partial k_t^* / \partial k_g \geq 0$.

PROPOSITION 2: *Provided that k_p^*, and k_g are positive, public R & D contracting will result in some crowding out.*

Proof: From the re-arrangement of (5) suggested in the proof of Proposition 1 we can obtain the following derivative:

$$\frac{\partial k_t^*}{\partial k_g} = \frac{1}{1 - F'(\cdot)}$$

We have already established that $F'(\cdot) < 0$, therefore $\partial k_t^* / \partial k_g < 1$

PROPOSITION 3: *The relationship between the average cost of capital to the firm with a positive level of government R & D funding and that with completely private funding is ambiguous.*

[11] This assumption is analytically convenient but not restrictive. It is a straightforward exercise to show that allowing the scale of A to vary in response to k_g does not affect any of the results qualitatively. The reason is that the scale of A and B always move in the same direction following a change in k_g.

[12] I have followed Jensen and Long [7], and Greenberg et al. [3] in assuming that the effect of the investment on λ_m is of second-order.

Proof: Rewrite the valuation equation (4) in the form:

$$V_i = \frac{1}{r}\,[\bar{x}_i - \phi_i] \tag{6}$$

where $\bar{x}_i = \bar{x}_a + \bar{\theta}f(k_t, \bar{x}_a) + \bar{\rho}k_p + \delta k_g$, and $\phi_i = \lambda_m \sigma_{im}$. Now, rearrange (6) as:

$$\bar{x}_i / V_i \equiv r_i = r + \phi_i / V_i \tag{7}$$

where r_i is the rate of return or average cost of capital to firm i. Define the covariance of the rates of return on firms i and j as $\hat{\sigma}_{ij} = \sigma_{ij}/V_i V_j$. Using the definition of λ_m as $\lambda_m = V_m(r_m - r)/\sigma_m^2$ we can expand (7) to:

$$r_i = r + \beta_a(r_m - r) + \beta_{sb}(r_m - r) \tag{8}$$

where $\beta_a \equiv \hat{\sigma}_{am}/\sigma_m^2$, $\beta_{sb} \equiv \hat{\sigma}_{sbm}/\hat{\sigma}_m^2 \equiv V_m[f(\cdot)(\sigma_{\theta m} + \sigma_{\theta a} + 2k_p\sigma_{\theta\rho}) + k_p(\sigma_{\rho m} + \sigma_{\rho a}) + f(\cdot)^2\sigma_\theta^2 + k_p^2\sigma_\rho^2]/V_i\sigma_m^2$. The term $\beta_i = \beta_a + \beta_{sb}$ is known in the finance literature as firm i's beta coefficient and is high for firms with a high level of undiversifiable risk. The term β_a can be interpreted as the β which would prevail if no R & D investment took place. The term β_{sb} is the additional cost of capital that the firm must pay for producing the spillover and product B. This additional cost of capital is an increasing function of both k_t and k_p. A unit of k_g increases k_t and decreases k_p so that, without explicit knowledge of the variance and covariance terms, the impact of k_g on β_{sb} and thereby on the average cost of capital is ambiguous.

The interpretation of Propositions 1–3 is quite straightforward. Private investment in the technologically-intensive good generates two outputs, a high-technology good and a spillover, both of which add to the risk and expected return of the firm. With no public funding, the risk and return characteristics of the two outputs cannot be separated and the firm will invest until the marginal increase in return averaged across the two outputs is equal to the marginal increase in risk averaged across the two outputs, multiplied by the market risk premium λ_m. A fixed-price government R & D contract enables the firm to separate the risk and return characteristics of the two outputs to some extent by offering it the spillover without the high-technology good. Provided that the ratio of marginal return to marginal risk from the spillover is greater than the market price of risk, the firm will accept the contract. To restore its overall marginal ratios to their optimal values, the firm will need to decrease the amount of its private investment. While private investment falls, the total investment of private plus government rises. This is to be expected since prior to receipt of the government contract, the firm is constrained in its ability to maximize value by its inability to separate the contributions to its value of the high-technology good and the spillover. The government contract reduces the size of the distortion to some extent.

It should be emphasized that these propositions do not require the government and private R & D goods to be identical in either their physical or risk and return characteristics. The only restrictive assumption required is that a dollar invested in technology yields a spillover to the standard product that has expected value $\bar{\theta}f(k, \bar{x}_a)$ and variance σ_θ^2 regardless of whether the technlogy is private or public. The actual physical product of the spillover (improved techniques, materials and so on) will almost certainly vary between private and public projects but it is assumed that the dollar value and stochastic properties will not.

II. A Case Study: The Transport Industry

This section presents the results of a preliminary investigation of the implications of the theory constructed in Section I. The results are tentative since the data do not come from a random sample and several simplifying assumptions are made. The data consist of cross-section observations for 46 firms in the United States transport industry. This industry was chosen for two main reasons: the relative homogeneity of the industry structure, and the accessibility of public R & D spending statistics by firm from NASA and DOD.

The theoretical framework of Section I provides a number of hypotheses which are testable in principle. Proposition 2 suggests that private R & D spending by a firm will be a decreasing function of the size of government contracts awarded to the firm. Proposition 3 suggests that the cost of capital to each firm will be an increasing function of total R & D spending and a decreasing function of private R & D spending. The proof of Proposition 3 also suggests that the risk parameter, or β-coefficient of any given firm will vary over time as a function of the level of public R & D funding to the firm. While each of these forms part of a more general test of the model, it is the first that is of prime importance for evaluating the effects of public funding on the expected total stock of technology-intensive capital. The work reported in this section focuses entirely on this test.

It should be emphasized that a test of Proposition 2 is not a test of the ex post contribution of public R & D to productivity or efficiency—it is a test of the extent to which public R & D crowds out private R & D at the exploratory investment stage. Whether or not the investment, either government or private, is consistently successful ex post in adding to the stock of working technology-intensive capital is a separate question.

Proposition 2 follows from Equation (5) which states that private R & D spending is an increasing function of the scale of the firm, $\bar{x}_a$, and a decreasing function of public R & D spending, k_g, received by the firm. The function itself is a complex interaction of variances, covariances, and the properties of the spillover function. In order to estimate the relationship between k_p and the independent variables $\bar{x}_a$ and k_g, it is necessary to assume that the variance and covariance terms are the same across all firms in the transport industry. This requires that all firms in the industry face essentially the same set of investment opportunities, at least in terms of their risk and return characteristics.

A. The Data

The firms in the sample were chosen from the classifications in the 3 July 1978 edition of *Business Week* (the annual R & D survey). The sample was then restricted to firms listed on the New York Stock Exchange and a further four companies were deleted due to the unavailability of private R & D figures. Data about government R & D contracts to each of the firms in the sample were made available by NASA and DOD.

The other relevant series is $\bar{x}_a$. The role of the variable $\bar{x}_a$ in the spillover function is that of a scaling factor. There are several possibilities for scaling the firm. The two most likely candidates are sales and some measure of cash flow (e.g. net income plus depreciation). Since the two are highly correlated (the correlation coefficient between the two over the sample is .972) this section will report only the results using sales. All three data series are available on a consistent basis from accounting data for the years 1976 and 1977. By treating the two separate sets of annual observations on each firm as though they were separate companies, the data set is expanded to 92 observations.[13]

B. The Results

The relationship in Equation (5) was estimated using a first-order linear approximation. A second-order approximation was also tried but the higher-order terms were all insignificant while the overall sign pattern, coefficient size, and equation fit were substantially unaltered. The results of the linear approximation are reported in Equation A in Table I.

Both sales and government contracts are significant at the 99 percent confidence level and enter with their expected signs. The constant term is insignificant. The crowding-out effect of government funding suggested by this equation is nonetheless quite small—an increase in public R & D of one dollar decreases private R & D by approximately eight cents, thus adding around ninety-two cents to the total R & D effort; an encouraging result for supporters of public funding as a means of increasing the national investment in technology.

The big range of firm size (from US$34 million to US$55,000 million) suggests the possibility that the errors may be heteroscedastic. The sample was divided into the 46 biggest firms and the 46 smallest firms and tested for heteroscedasticity according to the test proposed by Goldfeld and Quandt [2]. The null hypothesis of homescedasticity is rejected overwhelmingly at the 99 percent confidence level.[14] The results of the two equations for big and small firms are reported as Equations B and C in Table I. The effects of both sales and government contracting on private R & D are larger for larger firms. Furthermore, the model fits the data better for large than for small firms. These results are interesting in their own right and reflect the dominance of large firms in both private and government R & D. The stronger relationship between sales and private R & D for large firms possibly reflects economies of scale in R & D or barriers to entry into the R & D field, such as set-up costs in terms of both equipment and personnel. Too much emphasis, however, should not be placed on these two equations since they too are likely to suffer from heteroscedasticity.

The final equation, D, in Table I is a re-estimation of Equation A corrected for heteroscedasticity. Equation D utilizes the assumption that the variance of firm i is directly proportional to its size, proxied by sales. It is estimated by weighted least squares using the square root of sales as the normalizing variable.

Equation D has desirable properties in terms of its estimates of the coefficients and their standard errors, and is therefore the preferred equation. Its implications, however, are essentially the same as those from Equation A. The coefficients on

[13] Estimating the equations for the separate data sets 1976, 1977, and an average of the two years did not alter the results significantly.

[14] The test is based on the statistic $Z = e_1'e_1/e_2'e_2$ where e_1 is the residual vector for the 46 large firms and e_2 is the residual vector for the 46 small firms. The statistic Z is distributed $F(44, 44)$ and from Equations B and C in Table I, Z = 308.7. The critical value of F at the 5% level is 1.65 and at the 1% level is 2.04.

Table I

The Effects of Government R & D Contracting on Private R & D

	Const.	Sales	k_g	$\bar{R}^2$
A. Full Sample	−8.478	.028	−.081	.958
	(6.242)	(.0006)	(.035)	
B. Big Firms	−13.125	.028	−.074	.951
	(14.241)	(.0009)	(.052)	
C. Small Firms	−.171	.015	−.061	.587
	(1.044)	(.0019)	(.018)	
D. Corrected for Heteroscedasticity	−2.823	.026	−.083	.956
	(1.495)	(.0013)	(.032)	

Notes: (a) In each equation the dependent variable is k_p;
(b) Standard errors are reported in brackets; and
(c) Equation (D) is estimated by weighted least squares using the square root of sales as the normalizing variable. It is constructed by dividing both sides of the estimating equation A by the normalizing variable. The value for $\bar{R}^2$ in this equation refers to the implied unweighted estimates.

sales and k_g are both significant at the 99 percent confidence level and both have their expected signs. As in Equation A, the coefficient on k_g suggests that each dollar of public R & D spending crowds out eight cents of private R & D spending.

III. Conclusion

This paper has attempted to provide some insight into the question of how government R & D spending affects private R & D spending and thereby the total investment in technology. The problem was approached within the context of the capital asset pricing model in which the firm views investment projects in terms of their risk and return characteristics. The firm was assumed to produce jointly an established product and an R & D-intensive product, where the latter generates an additional output of technology, or spillover, that is used as an input into the former. By investing in R & D, the firm alters its risk and return characteristics in two ways: through the expected profits from the sale of the R & D-intensive good, and through the expected profits from the spillover. In this model government mission-oriented R & D contracting affects the firm by enabling it to separate to some extent these two sources of risk and return. The main implication of the analysis is that while some crowding-out of private R & D is likely, it is almost certain to be incomplete; that is, an increase in government funding should always increase the total R & D effort. The empirical evidence from the U.S. transport industry supports the model and suggests that each dollar of government funding adds around 92 cents to total R & D spending; crowding out private investment by as little as eight cents in the dollar.

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