NBER WORKING PAPER SERIES

# PRIVATE INVESTMENT IN R&D TO SIGNAL ABILITY TO PERFORM GOVERNMENT CONTRACTS

Frank R. Lichtenberg

Working Paper No. 1974

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
July 1986

Financial support from the National Science Foundation (via grant PRA 85-12979 to NBER), and from the MacArthur Foundation Faculty Research Program at Columbia University, is gratefully acknowledged. Donald Siegel provided capable research assistance. Remaining errors are my own. The research reported here is part of the NBER's research program in Productivity. Any opinions expressed are those of the author and not those of the National Bureau of Economic Research.

Working Paper #1974
July 1986

# Private Investment in R&D to Signal Ability to Perform Government Contracts


## ABSTRACT

Official government statistics on the "mission-distribution" of U.S. R&D investment are based on the assumption that only the government sponsors military R&D. In this paper we advance and test the alternative hypothesis, that a significant share of privately-financed industrial R&D is military in orientation. We argue that in addition to (prior to) contracting with firms to perform military R&D, the government deliberately encourages firms to sponsor defense research at their own expense, to enable the government to identify the firms most capable of performing certain government contracts, particularly those for major weapons systems. To test the hypothesis of, and estimate the quantity of, private investment in 'signaling' R&D, we estimate variants of a model of company R&D expenditure on longitudinal, firm-level data, including detailed data on federal contracts. Our estimates imply that about 30 percent of U.S. private industrial R&D expenditure in 1984 was procurement- (largely defense-) related, and that almost half of the increase in private R&D between 1979 and 1984 was stimulated by the increase in Federal demand.


Frank R. Lichtenberg
Graduate School of Business
Columbia University
726 Uris Hall
New York, NY 10027

# Private Investment in R&D to Signal Ability to Perform Government Contracts

Frank R. Lichtenberg

The U.S. defense buildup that began in 1979 has intensified the public debate about the size and rate of growth of the defense budget in general, and defense-related R&D expenditure in particular. A key issue in the debate about defense R&D is whether too large or too small a fraction of the nation's scientific and technical resources are being allocated to defense, as opposed to civilian, research. If there were extensive technological spillovers from defense-oriented research to civilian-oriented research, the distinction between the two would be neither very meaningful nor very important. In our view, however, there is little empirical evidence to support the claim that much recent or planned military research is likely to benefit civilian technologies.[1] Explanations for the low and possibly declining rate of spillover have been offered by Thurow (1986), among others.

If the tradeoff between the nation's ability to promote military and civilian technological progress is fairly steep, a correct accounting of the distribution of national investment in R&D by "mission" (defense vs. civilian) appears to be a worthwhile objective. I submit that at least some of the government's official statistics concerning the mission-distribution of R&D are misleading in this regard. According to data

[1] A brief survey of some empirical evidence on the incidence of spillovers from military to civilian research is presented in Lichtenberg (1985).

published by the National Science Board and the National Science Foundation, only the government, and not private industry, sponsors (finances) defense-related R&D; the private sector sponsors only civilian R&D. The purpose of this paper is to provide a theoretical explanation for, and to test empirically, the alternative hypothesis, that industrial contractors sponsor a significant amount of military R&D, due to incentives deliberately provided to them by the government to do so. We also provide estimates of the quantity (and share) of private R&D investment that is induced by federal procurement and, hence, is largely military in orientation.

As we observe in the next section, previous investigators have provided various kinds of evidence of private investment in R&D oriented toward defense and other federal government missions. Such investment occurs because the government establishes rewards for, and subsidizes the costs of, procurement-related R&D expenditure. What has not, in our opinion, been adequately explained, is why it is in the government's interest to encourage this investment. After all, the government can directly contract with firms to perform R&D on its behalf. The government contracted with industrial firms for $20.2 billion worth of R&D in 1983, almost one-third the total value of R&D performed by these firms. Since it engages in such extensive contracting for R&D services, why does the government evidently also provide firms with incentives to sponsor relevant R&D on their own? From a different perspective, under what conditions might the government seek to induce private investment in a particular area of R&D, rather than directly contracting for this R&D?

We attempt to provide answers to these questions in Section II of the paper. Our explanation is based on the assumption that in some cases the government has imperfect information about the ability of various potential contractors to perform a given R&D contract (or other contracts involving great technical uncertainty). In these cases, the government invites firms to "signal" their ability to perform the contract: it sponsors "design and technical competitions." Signaling entails the utilization of contractors' R&D personnel and facilities. For a signal to effectively convey information about contractor ability, the cost of generating the signal (R&D investment) must be at least partially borne by the prospective contractor, rather than by the government.

In Section III of the paper, we propose an econometric model for testing the hypothesis that federal procurement in general, and procurement via design and technical competition in general, induces considerable private R&D investment. Variants of this model are estimated on longitudinal, firm-level data on R&D investment, sales, and government contracts obtained from the Compustat General Annual Industrial File and the Federal Procurement Data System. In Section IV we report estimates of the model and compute from them the aggregate quantity (and share in total R&D investment) of private R&D induced by federal procurement. A summary and concluding remarks are presented in Section V.

## II

We begin this section by citing two important pieces of evidence that a significant share of private R&D investment is defense-related. We then develop an explanation of why the government seeks to promote private investment in military R&D, in addition to directly contracting for such R&D.

The first piece of evidence consists of budgetary data on the government's Independent Research and Development (IR&D) program.[2] Under the provisions of this program, DoD and NASA contractors are permitted to charge part of the costs of their R&D efforts that are not supported by specific contracts as overhead on cost-reimbursement contracts. Major defense contractors negotiate advance agreements with these agencies that impose ceilings on the amount of R&D expense for which contractors can be reimbursed. In order for the costs of a project to be eligible for reimbursement under the IR&D program, the project must be demonstrated to have "potential military relevance." Also, in order to have any of its R&D expenses reimbursed, a company must have some DoD or NASA contracts. Major defense contractors reported having incurred total IR&D costs of $3.9 billion in 1983. This represents about 9.2 percent of NSF's estimate of $42.6 billion for "company and other funds for R&D" (i.e., non-contract R&D) in industry in 1983. Firms were reimbursed for $1.6 billion (about 40 percent) of this expenditure by DoD and NASA. According to the IR&D budget data, then, firms spent $2.3 billion on projects with "potential military relevance" for which they were not reimbursed in 1983.

A second type of evidence is provided by Scherer's (1984) analysis of "linked" R&D and patent data of the largest R&D-performing companies. A team of students supervised by Scherer attempted to classify each of about 15,000 U.S. patents (obtained by 443 companies between June 1976 and March 1977) by "industry of use," i.e., to identify the sector(s) of

[2]See Reppy (1977) and Winston (1985) for detailed discussions of the IR&D program.

the economy in which (most intensive) use of the invention was anticipated. Scherer "assigned" R&D-expenditures to each patent by assuming that the value of R&D "embodied in" (invested to obtain) any particular patent was equal to the average R&D expenditure per patent of the line of business receiving the patent. This assignment procedure enabled classification of R&D expenditures, as well as of patents, by industry of use. Two of the industries of use defined by Scherer were "defense and space operations" and "government, except postal and defense." He estimated the value of company-sponsored R&D "used" by these sectors to be $1206.3 million and $378.7 million, 11.3 and 3.6 percent, respectively, of the total amount of company-funded R&D ($10.64 billion) attributed to these companies.[3] Thus, according to Scherer's methodology, the federal government is the primary beneficiary of about 15 percent of company-sponsored industrial R&D expenditure. These estimates are based, of course, on judgments concerning the classification of patents by industry of use, and on the imputation of "average" R&D expenditures per patent to specific patents.

Thus, both the IR&D budget data and the "linked" patent R&D data suggest that a non-negligible fraction -- on the order of 10 percent -- of private R&D investment is oriented toward defense or other federal missions. The econometric evidence presented in the next section suggests that the fraction is significantly larger and has increased substantially in recent years. Before considering that evidence, however,

[3]These estimates were obtained using what Scherer termed the "private goods" assumption, according to which a patent (and its associated R&D expenditure) benefitted (was assigned to) only one, rather than several, industries of use.

we seek to explain why the government provides financial incentives for firms to sponsor such research, in addition to, or instead of, directly contracting with them. As anticipated above, our explanation is based on the premise that the goverment has imperfect information about the ability of potential contractors to perform specific R&D projects.

The idea that the government's information in the context of R&D contracting is incomplete is not a novel one. Rogerson (1984) developed a theory of optimal R&D contracting predicated on the assumption that it is costly or infeasible for the government to monitor either the <u>outcome</u> of a project performed by a contractor (i.e., how "successful" the project was in achieving its objectives) or the <u>effort</u> (expense) invested in the project. Rogerson argued that if it is difficult for the government to observe the outcome of the project, and if the financial reward to the contractor is greater if he reports a successful outcome than if he reports an unsuccessful one, then the contractor has an incentive to misrepresent the outcome, i.e., to overstate the degree of success. In practice, a contractor is likely to earn higher rewards if he reports a successful outcome; in particular, he is likely to be awarded "follow-on" contracts for further development, and possibly also for production, training, maintenance, spare parts, and so forth. To eliminate the contractor's incentive to distort the outcome of the project, the government could offer a fixed fee for performance of R&D contracts, i.e., a reward that is independent of the reported outcome. (Presumably, under this scheme follow-on contracts would not be awarded to the R&D performer, even if the project were a success.) However, this mode of contracting suffers from a number of defects, one of which arises for the following reason. Suppose, as Rogerson does, that the government has difficulty monitoring contractor effort. Assume that the probability of a successful outcome increases with the quantity of effort. If the contractor's reward does not depend upon the reported outcome, the contractor maximizes his net income by expending minimum possible (perhaps zero) effort on the project, and by (truthfully) reporting failure. As Rogerson observes, the difficult problem facing the government is to design an optimal contract that "achieves a balance between the three competing concerns of inducing effort, inducing truthful revelation, and allocating risk."[4]

The work of Rogerson and others on optimal R&D contracting addresses the important problem of how the government should contract with a specific firm, given the difficulty of monitoring the effort on or outcome of the project. But due to its incomplete information, the government faces an additional difficulty, one that is logically prior to that of writing an optimal contract: choosing the right firm with which to contract. We assume that both R&D projects and prospective R&D contractors (firms) are heterogeneous: some firms are more qualified to perform a given R&D project than other firms. By more qualified, I mean that they will have a higher probability of success from a given effort, or will require less effort to achieve a given probability of success. In the case of some projects, the government may know (or at least believe that it knows) the identity of a firm that is best qualified to perform the project. In these situations the government may contract with the firm it has identified on a noncompetitive basis. Only about 30 percent of the value of DoD R&D contracts are awarded on this basis,

---

[4]Rogerson (1984), p. 4.

however.[5] In the case of the remaining 70 percent of R&D contracting, the government does not know (although it may have subjective probability beliefs concerning) which of a relatively small number of firms is best qualified to perform the contract. How can the government discover the identity of the firm most capable of performing the contract?

The market for government R&D contracts is by no means the only market in which the buyer has imperfect information about the quality of products or services offered by different sellers. Employers have incomplete knowledge of the ability of (hence the quality of labor services provided by) job applicants; consumers are uncertain about the quality of various brands of a product. A number of theoretical models of markets characterized by this kind of imperfect information show that it is equilibrium behavior for sellers to invest in acquiring, and for buyers to rely on, signals of quality and ability. Spence (1974) has argued that employers may use information about job applicants' investments in education as signals of their underlying ability, and thus make wage offers on the basis of educational attainment. Kihlstrom and Riordan (1984), developing ideas advanced by Nelson, argue that advertising expenditures may signal unobservable product quality to consumers. We hypothesize that prospective federal contractors signal their ability to perform R&D and related contracts by producing elaborate technical proposals, which entails utilization of R&D personnel and facilities. In order to demonstrate the applicability of the signaling

---

[5] The 30 percent figure reflects our treatment of follow-on awards after design and technical competition as competitive contracts. Although these contracts are officially classified as noncompetitive, since they are awarded to the winner of design and technical competitions, we regard them as being awarded on a competitive basis.

concept to the market for government R&D contracts, it is useful to briefly review Spence's model of job market signaling. We then descibe the government's principal method of awarding R&D contracts, procurement by design and technical competition. We postulate that the government sponsors these competitions in order to encourage contractor signaling.

Spence hypothesizes that employers are willing to make high wage offers to high-ability job applicants, and low offers to low-ability applicants, but that employers cannot directly observe applicant ability. In the absence of that information, employers may make wage offers to applicants based on the value of an observable atttribute which, they believe, signals ability. Spence argued that for an attribute to function as a signal of ability, three conditions must be satisfied: (1) the value of the attribute must be subject to the applicant's control; (2) it must be costly (to the applicant) to increase the value of the attribute; and (3) the cost of increasing the value of the attribute must be lower for applicants of higher ability.[6] Spence hypothesized that educational attainment functions as a signal of ability in the job market. Employers make subjective evaluations of job applicants' ability (and hence make wage offers) on the basis of the quantity of investment in education applicants have made: higher wage offers are made to individuals with more education. High-ability workers find it worthwhile to invest in education in order to secure higher wage offers, but due to their higher costs of acquiring education, low-ability workers do not. An interesting

---

[6]Instead of assuming asymmetry of costs of signalling (and equality of returns), Kihlstrom and Riordan assume asymmetry of returns -- greater returns to signalling by the high-quality seller -- and equality of costs.

feature of signalling models is that multiple equilibria often exist: any of a number of initial employer beliefs (about the relationship between the value of the signal and ability) may be self-confirming. Some of the equilibria may be Pareto-inferior to others. In the signalling model (high-ability) individuals invest in education not because it increases their productivity (which is the motive for investment in education according to human capital theory) but "merely" because it signals their (exogenously) higher productivity. It is true that the social rate of return to educational investment will be positive if signalling improves the allocation of applicants to jobs, placing high-ability individuals in jobs requiring high ability, and conversely. But the private rate of return is likely to exceed, perhaps by a substantial amount, the social rate of return, resulting in significant overinvestment in education.

Let us return to consider the problem of government selection of an R&D contractor under uncertainty about contractor qualifications. When the government is (initially) unable to identify the most qualified contractor, it sponsors something called a design and technical competition. The following is a brief characterization of of the modus operandi of design and technical competitions; a signaling interpretation of these competitions is provided below. The competition begins "officially" when a federal agency (DoD or NASA) issues a formal Request for Proposals (RFP). Many analysts have noted, however, that potential contractors are aware of the government's interest in particular areas of technology, and attempt to influence the "shape" of government demand for innovations, long before the publication of RFP's. Indeed, a contractor who first learned about a project from an RFP would be effectively out of the running for that project. Danhof has observed that "it is an important part of the contractual process that the firm's representatives participate in the informal discussions that long precede the establishment of requirements and in the debate as alternatives are narrowed."

In the case of DoD procurement, the mean and median number of firms to submit proposals in response to an RFP is about three or four. In four of the seven (presumably "representative") DoD competitions considered by Fox, three firms submitted proposals; in two of the competitions, four firms did, and in one competition, seven firms. Danhof notes that about one out of four competitive proposals for aerospace (DoD) contracts is successful. About one of every nine bids for competitive NASA contracts is successful.

In view of the fact that the RFP's are on the order of 1100 to 2500 pages in length, it is perhaps not suprising that the typical proposal ranges in length from 23,000 to 38,000 pages. The five proposals submitted under the C-5A program totalled 240,000 pages. The proposals generally consist of three main sections. The technical section is the largest, comprising about two-thirds of the total proposal. In this section, the company explains how it plans to meet the performance specifications set forth in the RFP. In the management section, the company attempts to convince the government that it has the necessary manpower and the appropriate management and control techniques to successfully perform the project. Cost estimates and supporting documentation are presented in the cost section of the proposal.

Once the proposals for a given procurement program have been submitted, an elaborate review process begins. Various committees assign "scores" to numerous aspects of each company's proposal, and the individual scores are combined using a predetermined set of weights. Proposal evaluation appears generally to take about three months, during which time tens of thousands of government-employee manhours are engaged in the "source-selection" process. The firm that submits the proposal receiving the highest score is generally awarded the contract.

We believe that it is both natural and useful to interpret design and technical competitions as signaling phenomena. The signal of contractor ability to perform the contract that the government relies on is the score on the technical proposal. Each firm has its own (possibly stochastic) "score cost function" (and a dual "score production function") that relates the cost of preparing the proposal to the (expected) score to be received by the proposal. We hypothesize that there are positive and increasing marginal costs of improvements in the score. Following the logic of the Spence model, in order for the score on the proposal to effectively signal ability to perform, two additional conditions must be satisfied. First, the cost of preparing a proposal of any given score must be lowest for the most capable contractor. That this should be the case seems quite plausible. Second, the cost of preparing the proposal must be at least partially borne by the contractor. The government could, after all, contract with firms to produce proposals. But if all costs of proposal preparation were borne by the government, proposals would not effectively convey information about contractor ability. Evidently, contractors must place some of their own resources "at risk" if they are to demonstrate their capability to the government. Although it would be inappropriate for the government to underwite all contractor costs of proposal preparation, it might be appropriate for it to <u>subsidize</u> such expenditures if it believed contractors would under-invest in signaling in the absence of subsidies.[7] The existence of the IR&D program, which, we indicated above, subsidizes private military research expenditure, might perhaps be justified on these grounds: without IR&D reimbursements, design and technical competitions might yield an insufficient quantity of information about contractor ability.[8]

We have argued that the government sponsors design and technical competitions, which elicit signaling investments by potential contractors, in order to acquire information about contractor qualifications to provide R&D and related services and products. There is, however, an alternative hypothesis that could account for the government's use of this method of procurement. According to this view, federal agencies sponsor these competitions not in order to acquire information about contractor ability -- they know in advance of the competition which firm they want to hire -- but in order to impress (or signal) Congress that they are committed to competition in procurement. Judging from the periodic Congressional hearings and reports on the subject (see, for example, U.S. Congress (1969)), there is strong Congressional demand for competition in procurement, and procurement officals must pursue polices that at least <u>appear</u> to be consistent with this objective.

---

[7]The socially optimal (efficient) quantity of signaling investment is the quantity at which the marginal (expected) benefit (assumed to be diminishing) of the information transmitted equals the marginal cost (assumed to be increasing) of transmitting the information. The marginal benefit is measured in terms of the increase in the probability of choosing the most qualified firm, and the increase in the probability of success (or reduction in costs) resulting from choosing the most qualified firm.

[8]If the rate of subsidy varies across firms, as it appears to do under the IR&D program, it is important that it not be very negatively correlated with contractor ability. If the least capable firms receive

Roberts (1964) has argued that, in practice, source selection does not operate according to the three tenets of official procurement policy: (1) maximum competition; (2) objective (numerical) proposal evaluation; and (3) independent, multilevel review. With regard to the second two principles, he notes first that scores on technical proposals essentially reflect evaluators' prior beliefs about contractor ability, and are scarcely influenced by the merits of the proposal. He also observes that there are strong political pressures for higher-level reviews of source-selection decisions to endorse (rubber-stamp) the actions of lower-level reviews. But his analysis of a sample of 41 DoD R&D contract awards does not suggest an absence of competition in the case of most contracts. That there is generally effective competition is implied by the following data. The technical initiator of an R&D project typically provides a list of "recommended firms" for the project. Edwards reports the following distribution of 41 R&D contracts, by number of recommended companies:

| Number of Companies Recommended | Number of Contracts |
|---|---|
| 1 | 6 |
| 2 or 3 | 9 |
| 4 to 21 | 26 |
| | 41 |

Thus, at least two firms were recommended in the case of 35 out of 41 (85 percent) of the contracts; at least four firms in the case of 63

---

the largest subsidies, they might be most likely to produce winning proposals.

percent.[9] Moreover, overall more than twice as many companies were solicited by the agency to submit proposals as were recommended by the technical initiator. An average of seven firms competed for contracts when only one firm was recommended; between 10 and 40 companies were solicited when two or three were recommended.

Of course, even if procurement officials know in advance which firm they want to perform the contract, and sponsor the design and technical competition merely to appease Congressional demand for (the appearance of) competition, unless firms also know that the outcome is predetermined, the competition would still be expected to elicit substantial R&D investment. And even if a firm is aware of its status as the "desired sole source" for a project (i.e., it is the only recommended firm), the firm may (correctly) perceive that it is required to submit a respectable technical proposal. Although desired sole sources are normally awarded the contract, Edwards cites a case in which a desired sole source lost because it "insulted the agency by sending in an 'advertising brochure.' Evidently, even a company that is 'in' can sometimes get too cocky," i.e., not devote sufficient effort to proposal development.

We conclude this section by briefly reviewing some case-study and anecdotal evidence regarding private R&D investment in pursuit of government contracts. Edwards describes an unpublished study by Thomas Allen at MIT of companies' proposal efforts related to 14 small ($30-$50 thousand) R&D contract awards. Allen found the total cost of all company proposal efforts in each competition ranged from 3 to 150 percent

[9] Edwards notes, however, that the lists of recommended firms were often not in alphabetical order, suggesting that procurement officials may have favored a subset of recommended firms.

of the direct cost of the contract awarded. Total proposal effort appeared to be related more to the number of bidders than to the value of the contract. Another study of 36 firms bidding for a single large R&D contract estimated that each bidder spent three to four thousand engineering manhours on its proposal. The estimated combined 45 to 60 engineering man-years reflects effort only at the prime contractor level; subcontractors must also generate technical data for prime contractors.

Estimates of the amount of R&D investment made by single firms in specific periods or competitions have occasionally been reported. Gorgol noted that "the Lockheed Aircraft Corporation was estimated to have spent about $75 million of its own money in the period 1964-66 to improve its competitive position in relation to the contract possibilities it viewed as likely to materialize. For example, more than 1000 employees were working on the C-5A proposal."[10] Lockheed continues to make such investments today: according to one of its vice presidents, Lockheed spent "in the low hundreds of millions of dollars," and assigned hundreds of its most able managers and technicians to research on the Advanced Technical Fighter, prior to submitting (along with six other companies) a 3000-page technical proposal for the aircraft project in February 1986.[11] Competition for "Star Wars" (Strategic Defense Initiative) research contracts has also elicited company R&D investment. In 1984, the government's Strategic Defense Initiative Organization "challenged companies to enter

---

[10] Gorgol (1972), p. 33.

[11] New York Times (1986).

what it called a horse race to devise the best Star Wars blueprint. A herd of 300 firms submitted initial applications, but SDIO narrowed the field to five, each of which will receive a $5 million grant to work on its designs." According to the head of GTE's Star Wars effort, "the price of admission to this game is much higher than usual." GTE normally lays out between $100,000 and $1 million of its own funds to develop a bid for a research grant, but as of October 1985 it had spent about $3 million on Star Wars proposals.[12]

While the anecdotal evidence is certainly consistent with our hypothesis of private investment in R&D to signal ability to perform government contracts, it is not adequate for formally testing the hypothesis or for estimating the quantity (and share) of private R&D investment undertaken for this purpose. A basis for formal testing and estimation is provided, however, by the econometric model presented in the next section.

## III

In this section we propose an econometric methodology for testing the hypothesis of, and estimating the quantity of, private investment in R&D to signal ability to perform government contracts. The methodology we propose is a generalization and extension of that used in previous investigations of the reduced-form relationship between company R&D expenditure (or other measures of innovative activity such as patents) and sales (or other measures of firm size such as assets).

---

[12] Time Magazine (1985).

If one is willing to regard a firm-size variable such as sales as a proxy for the extent of a firm's market (or growth in sales as a proxy for growth in demand for the firm's products-cum-innovations), then the "indivisibility" property of innovations suggests that innovative activity should be an increasing function of firm size. As Kamien and Schwartz (1982) observe, development costs are fixed costs, independent of the number of units of output produced, whereas more revenue is collected if output is larger. Hence, the larger the market, the greater the number of process and product improvements that are likely to appear profitable.

The objective of most previous studies of the relationship between inputs or outputs of innovative activity and firm size has been to test the Schumpeterian hypothesis that large firms tend to sponsor a disproportionate amount of innovation. In perhaps the most recent such study, Bound et al. (1984) computed regressions of the log of R&D expenditure on the log of sales and its square or the log of gross plant, using cross-sectional data for 1479 firms. They concluded that both very small and very large firms are more R&D intensive than average-size firms, and rejected the existence of any significant R&D threshold.

We are interested in investigating the effect of the composition, as opposed to the size, of demand for a firm's products on its R&D intensity, or propensity to sponsor R&D. A firm's total sales may be interpreted as the sum of its sales to each of its customers. In particular, it is the sum of its sales to the federal government (GOV) and to other customers (OTH). A regression equation of company R&D expenditure (CRD) on total sales (SALES) embodies the a priori restriction that government and other sales have the same effect on R&D expenditure. The most important respect in which we extend and generalize previous econometric studies of the determinants of private R&D investment is by relaxing this restriction, by classifying (disaggregating) SALES into its components GOV and OTH, and subclassifying GOV by method of procurement (competitive vs. other) and by commodity (R&D vs. other). By disaggregating sales in this manner, we purport to determine the extent to which government procurement in general, and procurement via design and technical competition in particular, stimulates private R&D investment.

In order to get consistent estimates of the (relative) effects of government and nongovernment demand on private R&D investment, we believe that two additional methodological extensions are necessary. The first involves testing for the presence of correlated firm- (and year-) effects by computing both random-effects and fixed-effects estimates of the following model using longitudinal, firm-level data:

$$(1) \quad CRD_{it} = \sum_j \beta_j X_{jit} + \alpha_i + \delta_t + u_{it} \qquad \begin{array}{l} i = 1, \ldots, N \\ t = 1, \ldots, T \end{array}$$

where $CRD_{it}$ represents company-sponsored R&D expenditure of firm i in year t, and $X_{jit}$ represents sales of type j by firm i in year t. The individual (firm) effects $\alpha_i$ reflect the influence of all unobserved time-invariant, firm-specific determinants, whereas the year effects $\delta_t$ capture the effects of changes over time in unmeasured determinants of CRD which are common to all firms. It is well known that there are two basic approaches to the estimation of model (1): "random effects" estimation and "fixed effects" estimation. In the random effects framework, the values of the individual and year effects are regarded as realizations of a random variable assumed to be distributed independently of the regressors and of $u_{it}$. In the fixed-effects framework, the $\alpha_i$ and $\delta_t$ are regarded as unknown parameters to be estimated. Under the null hypothesis that the individual effects are uncorrelated with the regressors, the random effects (RE) estimator is both consistent and asymptotically efficient, while the fixed effects (FE) estimator is consistent but inefficient. Under the alternative hypothesis of correlated individual effects, only the FE estimator is consistent. Clearly, which estimator should be chosen depends upon whether or not the null hypothesis is true. Fortunately, Hausman (1978) has developed a test for determining whether we should reject or fail to reject the null hypothesis. The test statistic is a measure of the distance between the FE and RE estimates; large values of this statistic should cause us to reject the null, and therefore to regard only the FE estimates as consistent. All of the models considered below were estimated by both RE and FE, and the Hausman test statistic based on the difference between these estimates was computed; in every case, the null hypothesis was decisively rejected. This is not very surprising since, as Hausman and others have noted, unobserved individual effects are unlikely, in general, to be uncorrelated with the regressors. In view of these findings, we report in Section IV only FE ("within-firm") estimates.

The second econometric extension that may be required to obtain consistent parameter estimates is estimation of the (fixed-effects) model by instrumental variables (IV) rather than by ordinary least squares (OLS). There are at least two reasons why one might expect OLS estimates of equation (1) to be inconsistent: simultaneous-equations bias, and errors-in-variables. The consistency of OLS estimates is predicated on the assumption that a firm's sales is exogenous relative to its R&D

expenditure. Although Mairesse and Siu (1984) were unable to reject the hypothesis that (total) sales is exogenous with respect to R&D, in view of our above characterization of design and technical competitions, it is quite plausible that the part of a firm's sales accounted for by government contracts (at least those awarded by design and technical competition) is partly determined by its (current or past) R&D expenditure. Thus, although total sales appears to be exogenous, it is unlikely that the (typically relatively small) government-sales component is.

Errors-in-variables (or, equivalently, errors in classifying firm sales into government and nongovernment components) arise mainly because, as discussed below, "government sales" is defined, perforce, as the value of federal prime contract actions (obligations) by firm and year. Error may result from both the fact that we are treating obligations as sales and from inability to account for subcontracting. There is a question as to when federal contract actions are "recognized" as revenue (sales) by the firm's accountants. We assume, in the absence of reliable information on this issue, that contract actions during a given year are reflected in that year's sales figure. With regard to subcontracting, it might be argued that subcontracting should be taken into account when classifying the firm's sales by customer. It might be desirable, for example, to partition the firm's sales into three components: sales directly to the government of products produced by the firm (i.e., prime contract awards minus subcontracts awarded to other firms); sales indirectly to the government (i.e., subcontracts awarded under other firms' prime contracts); and nongovernment sales. This kind of disaggregation would enable us to assess the extent of private R&D investment undertaken in pursuit of subcontracts. Unfortunately, there are at present no comprehensive and reliable data on the incidence of subcontracting at the firm level.[13] DoD data suggest that at least 38 percent of the value of prime contracts awarded to business firms is subcontracted.[14]

Let us briefly consider the consequences for our parameter estimates likely to result from errors in measuring government sales and, hence, in classifying total sales (assumed to be measured without error) into its components. First, because, as discussed above, the Hausman specification test indicated that the fixed-effects model was appropriate, we have adopted the "within-firm" estimator. Within this estimation framework (at least certain kinds of) "permanent" errors in measuring a firm's government sales are likely to be inconsequential; they will be absorbed by the individual effect for that firm. If we assume that the non-permanent component of the measurement error has the usual classical properties (i.e., uncorrelated with the "true" regressors and with the disturbance term), then a result reported by Griliches concerning the effect of measurement error in a multiple regression implies that the difference between the coefficients on government and nongovernment sales should be biased toward zero.[15]

---

[13]The Defense Acquisition Regulatory Council is currently considering an amendment to the DoD acquisition regulations that would require large prime contractors to submit quarterly statistical reports on first-tier contracting.

[14]See Department of Defense (1985), p. 81.

[15]This result can be established as follows. Suppose the true model may be expressed as

$$y = \beta_1 z_1 + \beta_2 z_2 + u$$

We attempt to address the problems posed by both potential endogeneity of government sales and errors in measuring government sales by computing instrumental-variable estimates (using putatively exogenous instruments for government sales), as well as OLS estimates, of our model of private R&D investment. A statistic measuring the distance between the OLS and IV estimates may be computed to test the null hypothesis that the assumptions required for consistency of the OLS estimator (i.e., government sales exogenous and measured without error) are satisfied.

In view of the fact that we are trying to measure the effect of exogenous shifts in the government's demand for each firm's products-cum-innovations, the instrument for firm i's actual government contracts in year t is an an estimate of its potential contracts in that year. Potential contracts is defined as the total (across all firms) value in year t of government contracts for two-digit FSC (Federal Supply Code) products and services that the firm <u>ever</u> sold to the government during

---

where y denotes company R&D expenditure, $z_1$ denotes true government sales, $z_2$ denotes true nongovernment sales, and all variables are measured as deviations from firm means. This model may be rewritten as

$$y = (\beta_1 - \beta_2)z_1 + \beta_2 z + u$$

$$= \gamma z_1 + \beta_2 z + u$$

where $z \equiv z_1 + z_2$ denotes total sales, and $\gamma \equiv \beta_1 - \beta_2$. Suppose $z_1$ is not observed but we observe a noisy indicator of $z_1$, x, related to it by

$$x = z_1 + \varepsilon$$

where $\varepsilon$ is a classical measurement error assumed to be uncorrelated with all other variables. Griliches shows that $\text{plim}(b_{yx\cdot z} - \gamma) = \gamma\lambda/(1 - \rho^2)$, where $\lambda \equiv \text{var}(\varepsilon)/\text{var}(x)$ and $\rho$ is the sample correlation coefficient between x and z. Thus, the least squares estimate of $\gamma$ is biased toward zero (estimates of $\beta_1$ and $\beta_2$ are biased toward equality). Also, provided that $\rho > 0$ (which is true for our sample), the bias is "transmitted," with an opposite sign, to the other coefficient: $\text{plim}(b_{yz\cdot x} - \beta_1) = -\rho[\text{bias } \gamma]$. See Griliches (1984), pp. 22-23.

the sample period 1979-1985. This may be expressed algebraically as follows:

$$POT_{it} = \sum_j D_{ij} * AGG_{jt}$$

where $D_{ij}$ = 1 if firm i ever sold product j to the government during the period 1979-1985;

= 0 otherwise

$AGG_{jt}$ = total (across firms) value of government contracts for product j in year t.

In order for $POT_{it}$ to be a valid instrument for $GOV_{it}$ in the CRD equation, the variables on the RHS of (2) should be exogenous relative to CRD. It seems reasonable to maintain that this is the case, i.e., that neither the lines of business the firm was engaged in, nor the aggregate volume of government procurement in those markets, was determined by the firm's rate of R&D investment.[16]

Testing certain hypotheses requires that we disaggregate government sales into various components, e.g., R&D and non-R&D. In order to have as many instruments as there are government-sales variables, the potential contracts variable is disaggregated into components in exactly the same way as the (actual) contracts variable. For example, potential contracts is divided into potential R&D contracts and potential non-R&D contracts, and these are used as instruments for actual R&D and non-R&D contracts, respectively.

---

[16]Obviously, using POT as an instrument is similar to using industry dummy variables as instruments, albeit in highly restricted form.

In the remainder of this section we provide a brief description of the data sources and procedures we have used to develop a data base suitable for estimation of the model outlined above. We have constructed a panel consisting of annual observations on company R&D expenditure, total sales, and government sales, for each of 187 firms during the years 1979-1984. Data on company sponsored R&D expenditure and on total sales of the company are taken from the Compustat General Annual Industrial File. Data on sales to the federal government (more precisely, on the net value of obligations to the firm under federal contract actions) are derived from the Federal Procurement Data System. The sample was constructed as follows. The Federal Procurement Data Center (FPDC) provided to the author a computer tape containing records of all federal (prime) contract actions of the 1500 industrial firms who had the largest total value of contracts during 1979-1984 (FPDC began operation in 1979). This tape contained records of almost 1.3 million contract actions. Each record indicates the month in which the contract action occurred, and the contract actions for each firm were aggregated to the annual level. We then matched the federal contract data, by firm and year, to the corresponding data on sales and company-sponsored R&D from the Compustat file. The Compustat file included data for only 187 out of the 1500 firms, many of which are not publicly traded companies. The firms that are included in both the FPDC and Compustat files (and therefore in our sample), though, tend to be the largest firms, measured either by CRD, sales, or value of federal contracts.

Table 1 presents summary statistics, by year, for our sample of firms, and, for purposes of comparison, selected published U.S. aggregate time-series. Total sample values of four data items -- company-spon-

Table 1

SAMPLE AGGREGATES AND COMPARISON NATIONAL DATA

(all amounts in billions of dollars)

AGGREGATES FOR SAMPLE OF 187 FIRMS

| YEAR | COMPANY-SPONSORED R&D EXPENDITURE | SALES | VALUE OF FEDERAL CONTRACTS | VALUE OF FEDERAL R&D CONTRACTS |
|---|---|---|---|---|
| 1979 | 17.8 | 748.8 | 41.1 | 7.8 |
| 1980 | 20.7 | 826.3 | 46.6 | 8.5 |
| 1981 | 23.6 | 908.4 | 56.8 | 9.2 |
| 1982 | 26.4 | 898.9 | 72.7 | 13.2 |
| 1983 | 29.0 | 931.2 | 79.3 | 15.0 |
| 1984 | 34.4 | 994.1 | 85.8 | 16.3 |

U.S. NATIONAL DATA

| YEAR[a] | "COMPANY AND OTHER FUNDS FOR R&D"[b] | SALES[c] | DoD PRIME CONTRACT AWARDS[d] | "FEDERAL FUNDS FOR R&D"[b] |
|---|---|---|---|---|
| 1979 | 25.7 | 1215.0 | 58.5 | 12.5 |
| 1980 | 30.5 | 1354.0 | 66.7 | 14.0 |
| 1981 | 35.4 | | 87.2 | 16.4 |
| 1982 | 39.5 | | 102.5 | 18.5 |
| 1983 | 42.6 | | 121.1 | 20.2 |
| 1984 | - | | 124.9 | |

[a] All data except DoD contracts on calendar-year basis; contract awards on fiscal-year basis.

[b] Source: NSF, R&D in Industry

[c] Net sales of R&D performang manufacturing companies.

[d] DoD Prime Contract Awards to Businesses for Work in the U.S. Source: DoD Prime Contract Awards Fiscal Year 1984, Table 3.

sored R&D, sales, value of federal contract actions, and value of R&D contract actions -- are shown. In 1983, these 187 firms reported a total of about $29 billion of company-sponsored R&D expenditure, or about 68 percent of NSF's estimate of U.S. aggregate industrial R&D expenditure.[17] The value of federal obligations to these firms for R&D was about $15 billion in 1983, which is 74 percent of NSF's estimate of federal funds for industrial R&D. The share of federal R&D in total (company + federal) industrial R&D expenditure is about a third in both sample and national data.

Recall that the method of contracting hypothesized to elicit (the most intense) private R&D investment is procurement by design and technical competition. Unfortunately, while the FPDS data do distinguish negotiated competitive procurement from other methods of contracting (e.g., negotiated noncompetitive or formally advertised procurement), they do not distinguish between the two principal methods of negotiated competitive procurement: price competition, and design and technical competition. Moreover, as the summary data published by DoD presented in Table 2 indicate, design and technical competitions account for only about one-fourth of the value of negotiated competitive contracts.[18] By

---

[17]Because company R&D expenditures that are reimbursed under the IR&D program are included in the NSF estimate but evidently excluded from the Compustat (10K-based) data, this fraction may understate the true share of these companies in national R&D expenditure.

[18]Although under 10 percent of the value of DoD contracts are officially recorded as <u>competitive</u> contracts awarded on the basis of design and technical competition, an additional 27 percent are designated "follow-on" contracts after design and technical competition, awarded on a noncompetitive basis to the winner of the competition. Hence in reality 37 percent of the value of DoD contracts are awarded, initially or eventually, on the basis of these competitions.

Table 2

Distribution of DoD FY1984 Negotiated

Competitive and Noncompetitive Procurement, by Method

(All figures in billions of dollars)

| Method of Procurement | All contracts | R&D contracts[1] |
|---|---|---|
| Competitive | | |
| Design and technical competition | 11.6 | 4.4 |
| Price competition | 35.0 | 0.4 |
| Follow-on after Competition | | |
| After design and technical competition | 31.6 | 4.6 |
| After price competition | 4.1 | 0.1 |
| Noncompetitive | 34.3 | 3.9 |
| Catalog or market price | 0.9 | * |
| Total, all methods | 117.6 | 13.4 |

[1]See text for definition of R&D contracts for purposes of this table.

*less than $0.05 billion.

cross-classifying contracts by whether or not they are competitive and by whether or not they are for R&D, however, we can isolate one class of contracts -- i.e., competitive R&D contracts -- which are awarded almost entirely on the basis of design and technical competition.[19] Thus if, as we hypothesize, design and technical competitions provide the greatest stimulus to private R&D investment, competitive R&D contracts should have the largest coefficient of the contract types which we can identify, given the data available to us. Since about one-fourth of competitive non-R&D contracts are awarded by design and technical competition, the coefficient on this category would be expected to be smaller in magnitude but still positive, and larger than the coefficients on other (follow-on and noncompetitive) contracts (whether or not for R&D), which are not awarded (at least directly) on the basis of a design and technical competition.

Finally, before turning to our parameter estimates, we thought it might be of interest to present data on the distribution of design and technical competition awards by product and service. These data provide an indication of the product fields in which the hypothesized company-sponsored signaling R&D is concentrated. Due to the data limitations cited above (i.e., inability to distinguish price competition from de-

---

[19] The distribution of contracts by method shown in the second column of Table 2 reflects the distribution of contracts which cite statutory authority 10 U.S.C. 2304(4)(11) ("experimental, developmental, test, or research") as their authorization for exception to the requirement for formal advertising. Whenever procurement officials wish to employ any method of procurement other than formal advertising, they must cite one of 17 possible reasons for not advertising enumerated in the U.S. Code. The eleventh such reason is that they are contracting for experimental, developmental, test, or research services. Contracts citing this reason are treated as "R&D contracts" for the purposes of Table 2.

sign and technical competition), we present data on the distribution of follow-on contracts (almost 90 percent of which follow design and technical competitions) rather than that of competitive contracts.[20] A list of the top 25 (4-digit Federal Supply Code) products and services, ranked by value of follow-on contracts, is presented in Table 3. These products and services account for over three-fourths of the total value of follow-on contracts. Not surprisingly, virtually all of these products and services are defense- and space-related.

IV

In this section we present and interpret estimates of the model of company R&D expenditures developed in the previous section. OLS and IV estimates of the fixed-effects version of equation (1) are presented in Table 4. We begin by disaggregating SALES into only two components: government contracts (sales), and nongovernment sales. In column (1a), OLS estimates of the regression of CRD on GOV and OTH are reported. The coefficient on GOV is about 2.26 times as large as the coefficient on OTH; moreover, the difference between these two coefficients is highly statistically significant.[21] IV estimates of the same model, using

---

[20] We note, however, that over 90 percent of the value of competitive R&D contracts are for defense and space R&D.

[21] The ratio of coefficients is similar to (slightly smaller than) that obtained when a similar equation was estimated on panel data for 88 business segments (lines of business) observed annually during the period 1978-1983. The ratio estimated from those data (derived from the Compustat Industry Segment File) was 2.67.

Table 3

Twenty-five Products and Services Accounting for Largest Value of Follow-on Contracts, Ranked by Value of Contracts

| Rank | Product or Service | Percent of Follow-on Contracts | Cumulative Percent |
|---|---|---|---|
| 1 | Aircraft Fixed Wing | 24.1 | 24.1 |
| 2 | Gas Turbines & Jet Engines Aircraft | 10.2 | 34.3 |
| 3 | Aircraft Rotary Wing | 4.5 | 38.8 |
| 4 | R&D-Missile & Space Sys-Eng Dev | 4.2 | 42.9 |
| 5 | Elct Countermeasure & Quick Reac Eq | 4.0 | 47.0 |
| 6 | R&D-Aircraft-Eng Dev | 2.6 | 49.6 |
| 7 | Guided Missiles | 2.1 | 51.7 |
| 8 | Guided Missile Systems, Complete | 1.9 | 53.7 |
| 9 | Airframe Structural Components | 1.9 | 55.6 |
| 10 | Miscl Aircraft Accessories Comps | 1.8 | 57.3 |
| 11 | Submarines | 1.7 | 59.0 |
| 12 | Combat Assault & Tactical Veh | 1.6 | 60.6 |
| 13 | Guided Missile Components | 1.4 | 62.0 |
| 14 | Nuclear Reactors | 1.4 | 63.4 |
| 15 | Radar Eq Airborne | 1.4 | 64.8 |
| 16 | Space Vehicles | 1.3 | 66.2 |
| 17 | Space Vehicle Components | 1.4 | 67.6 |
| 18 | R&D-Electronics & Comm Eq-Eng Dev | 1.4 | 68.9 |
| 19 | R&D-Space Trans Systems-Opsy Dev | 1.3 | 70.2 |
| 20 | Cruisers | 1.1 | 71.4 |
| 21 | Msc Elect & Electronic Components | 1.0 | 72.5 |
| 22 | Radar Eq Except Airborne | 1.0 | 73.5 |
| 23 | Misc Communication Eq | 0.9 | 74.4 |
| 24 | Guided Missile Subsystems | 0.7 | 75.2 |
| 25 | Prof Svcs/Systems Engineering | 0.7 | 75.9 |

"potential government sales" as an instrument for actual government sales, are presented in column 1b. The coefficient on OTH is unchanged by using an instrument for GOV, but the IV estimate of the GOV coefficient is almost twice as large as the OLS estimate. The IV estimates imply that a dollar of government demand (sales) induces over four times as much R&D expenditure as a dollar of nongovernment demand.

We performed the instrumental-variables test for errors-in-variables discussed by Hausman (1978), by running the regression of CRD on GOV, OTH, and the residual from the regression of GOV on its instrument (potential contracts). The coefficient on this residual was significantly different from zero ($t = 2.7$), indicating that we should reject the null hypothesis that GOV is measured without error (or, more generally, is uncorrelated with the disturbance). Consequently, only the IV estimates should be regarded as consistent.

We can use these coefficients to estimate the total quantity of private R&D expenditure induced by government sales; this estimate may be considered in relation to three different measures of R&D investment: (1) the quantity of private R&D expenditure induced by sales of all types; (2) the quantity of federal contract R&D; and (3) the quantity of IR&D investment. The quantity of private R&D investment induced by sales of a particular type is calculated as total sales of that type times the estimated (IV) coefficient on that type of sales. Estimates of the quantity of private R&D induced by both government and nongovernment sales are presented in Table 5. As indicated, the estimated share of government-sales-induced R&D expenditure in total induced R&D expenditure increased from 19.8 percent in 1979 to 28.7 percent in 1984. Moreover,

Table 4

OLS and IV Estimates of "Within" Regressions
of Private R&D Expenditure on Sales Classified by Type
Annual Data 1979-1984 for 187 Firms
(t-ratios in parentheses)

| Column | 1a | 1b | 2a | 2b | 3a | 3b | 4a | 4b |
|---|---|---|---|---|---|---|---|---|
| Estimation Technique | OLS | IV | OLS | IV | OLS | IV | OLS | IV |
| Variable | | | | | | | | |
| Nongovernment Sales | .023<br>(16.0) | .023<br>(15.8) | .024<br>(16.0) | .023<br>(15.7) | .023<br>(15.7) | .023<br>(14.9) | .022<br>(15.2) | .023<br>(13.9) |
| Government Contracts | .052<br>(6.5) | .098<br>(4.9) | | | | | | |
| R&D Contracts | | | .017<br>(0.6) | .080<br>(0.4) | | | | |
| Non-R&D Contracts | | | .058<br>(5.9) | .110<br>(3.8) | | | | |
| Competitive Contracts | | | | | .148<br>(5.6) | .417<br>(2.2) | | |
| Noncompetitive Contracts | | | | | .037<br>(4.2) | .047<br>(1.2) | | |
| Competitive R&D Contracts | | | | | | | .480<br>(5.4) | 1.498<br>(1.2) |
| Competitive Non-R&D Contracts | | | | | | | .147<br>(4.8) | .467<br>(1.8) |
| Noncompetitive R&D Contracts | | | | | | | -.204<br>(4.3) | -.452<br>(0.8) |
| Noncompetitive Non-R&D Contracts | | | | | | | .075<br>(6.7) | .057<br>(1.2) |
| Sum of Squared Residuals/1000 | 5568 | | 5561 | | 5482 | | 5315 | |
| Residual Degrees of Freedom | 928 | | 927 | | 927 | | 925 | |

almost half (48.7 percent) of the increase in total induced R&D expenditure during this period was induced by the increase in government sales.

Our estimates of government-sales-induced CRD investment, considered in relation to contract R&D expenditure, suggest that there is slightly more than 50 cents' worth of private, procurement-related R&D investment for every dollar of contract R&D. Stated differently, about one-third of the industrial R&D investment associated with government procurement is privately financed.

Because data on IR&D costs and reimbursements are available only at the national level, in order to compare government-sales-induced CRD expenditures to IR&D outlays, we need to estimate the former for the country as a whole, not merely for the sample of 187 firms. We do this by multiplying the government-sales coefficient (.098) by the aggregate value of DoD prime contract awards. (Because DoD accounts for only about 80 percent of the total value of federal procurement, this is probably a conservative estimate of the amount of private R&D investment induced by total federal procurement.) As indicated in Table 6, the resulting estimates of aggregate CRD expenditure induced by DoD prime contract awards are \$5.7 billion in 1979 and \$11.9 billion in 1983 (the last year for which we have IR&D data). These figures are about three times as large as the corresponding estimates of total IR&D costs incurred by industry (\$2.1 and \$3.9 billion, respectively). Moreover, the CRD-expenditure data upon which our estimate of the government-sales coefficient is based evidently exclude IR&D costs for which companies are reimbursed by DoD or NASA. These agencies typically reimburse about 40 percent of IR&D costs incurred. Hence it is to the total IR&D costs not reimbursed by federal agencies that our estimates of government-sales-

Table 5

Calculation of Share of Government-Sales-Induced CRD Expenditure in Total Induced CRD Expenditure

| Line | Description* | Year 1979 | Year 1984 | Change, 1979 to 1984 |
|---|---|---|---|---|
| (1) | Total government sales | 41.1 | 85.8 | 44.7 |
| (2) | Total nongovernment sales | 707.7 | 908.3 | 200.6 |
| (3) | Government-sales-induced CRD expenditure (.098 * Line (1)) | 4.03 | 8.41 | 4.38 |
| (4) | Nongovernment-sales-induced CRD expenditure (.023 * Line (2)) | 16.28 | 20.89 | 4.61 |
| (5) | Total Induced CRD Expenditure (Line (3) + Line (4)) | 20.31 | 29.30 | 9.99 |
| (6) | Share of Government-sales-induced CRD expenditure in Total induced CRD expenditure (Line (3) ÷ Line (5)) | 19.8% | 28.7% | 48.7% |

*All figures except those in line (6) in billions of dollars.

induced private R&D expenditure ought to be compared. As the comparison of the second and fourth lines of Table 6 indicates, unreimbursed IR&D costs are only about one-fifth as large as the value of privately-financed, procurement-related R&D expenditures implied by our model. The IR&D budget data appear to significantly understate the extent of private investment in defense-related R&D.

The model of CRD expenditure in which SALES is disaggregated into two components -- (all) government, and nongovernment -- is useful for estimating the amount of private R&D investment stimulated by federal procurement as a whole. We hypothesize that it is procurement by design and technical competition that provides the greatest stimulus to private R&D investment. As discussed above, we can test this hypothesis by estimating a version of the model in which government sales is cross-classified by method of procurement (negotiated competitive vs. other) and by commodity (R&D vs. other). Before presenting these estimates, we report estimates of models in which government sales is classified by a single attribute. These estimates are useful for purposes of comparison with previous econometric studies of the effect of federal procurement on private R&D investment. These studies have focused exclusively on the R&D component of procurement, and have not considered the effects of different methods of procuring R&D on private R&D expenditure.

Column 2 of Table 4 displays estimates of the CRD equation in which government sales is classified into R&D and non-R&D components. In the case of both the OLS and the IV estimates, the coefficient on government R&D is not significantly different from zero, whereas the coefficient on other government sales is positive and highly significant. One might

Table 6

Comparison of Estimates of Aggregate CRD Expenditure Induced by DoD prime Contract Awards with Total and Unreimbursed IR&D Costs Incurred by Industry

| Line | Description | 1979 | 1983 |
|---|---|---|---|
| (1) | Aggregate value of DoD Prime Contracts Awards | 58.5 | 121.1 |
| (2) | Estimated CRD expenditure induced by DoD Prime Contract Awards (.098 * Line (1)) | 5.7 | 11.9 |
| (3) | Total IR&D Costs incurred by industry | 2.1 | 3.9* |
| (4) | Total IR&D Costs incurred minus DoD and NASA reimbursements | 1.3 | 2.3* |

*Estimated

Sources: Line (1): see Table 1.
Lines (3), (4): Science Indicators, 1985, Appendix table 2-16.

well infer from these estimates that previous studies have been concerned with the portion of procurement which has the smaller and less significant effect on private R&D investment. But before we conclude that private R&D investment is essentially unresponsive to changes in the extent of R&D contracting, it behooves us to consider arguments and evidence in support of a subtler hypothesis: that some R&D procurement stimulates, and other R&D procurement depresses, the rate of private R&D expenditure. The insignificance of R&D procurement in general may be masking the offsetting effects of different methods of contracting for R&D services.

Estimates of the model in which government sales is classified by method of procurement are presented in column 3 of Table 4. In the case of both the OLS and IV estimates, the effect of competitive contracts is, as expected, substantially larger and more significant than the effect of the other types of contracts. The restriction that the two methods of procurement have the same effect on private R&D is decisively rejected: the t-ratio on the difference between competitive and other coefficients is 3.8 in the case of the OLS estimates and 2.0 in the IV case. The IV estimate of the coefficient on competitive contracts is about three times as large as the OLS estimate, and implies 42 cents of private R&D investment per dollar of competitive awards.

Estimates of the CRD model in which government sales is cross-classified by method of procurement and by whether or not the contract is for R&D are presented in column 4 of Table 4. Consider first the OLS estimates. Consistent with our hypothesis, the coefficient on competitive R&D contracts has the largest (and a highly significant) coefficient.[22] For this finding to be consistent with our earlier finding (in column 2) that R&D contracting in general has an insignificant effect on private R&D investment, non-negotiated-competitive R&D contracts should have a sizable negative effect on CRD. The estimates suggest that this is indeed the case: the coefficient on this component of government sales is negative and significantly different from zero. Evidently, the competitive award of R&D contracts tends to stimulate private R&D investment, but firms tend to reduce their own R&D spending when the value of R&D contracts awarded to them on a non-negotiated-competitive basis increases. Non-R&D contracts, on the other hand, appear to have a positive effect regardless of the method of contracting.

Whereas all of the OLS estimates in column 4 are highly significantly different from zero, the IV estimates are at best only marginally significant. Presumably, this lack of significance reflects the deterioration in quality (extent of correlation) of the "potential contracts" variables as instruments for their corresponding "actual contracts" counterparts as the extent of disaggregation of actual and potential government sales increases. Nevertheless, it is reassuring that the signs and relative magnitudes of the IV estimates in column 4 are generally similar to those of the OLS estimates.

---

[22] Since about 17 percent of competitive non-R&D contracts are awarded via DTC, a smaller but positive and significant coefficient on these contracts conforms with expectations.

V

Official government statistics on the distribution of the nation's R&D expenditures by "mission" are predicated on the assumption that only the government sponsors military R&D. But IR&D budget data, analyses of patents, and anecdotal evidence all suggest that a significant fraction of company-sponsored R&D expenditure is defense-related. We have argued that firms sponsor such research because the government deliberately provides them with incentives to do so, i.e., it establishes rewards for, and subsidizes the costs of, private military R&D investment.

Since the government simply contracts with firms to perform a substantial amount of R&D, the question arises why, and under what circumstances, does the government encourage private R&D investment rather than (or in addition to) directly contracting for R&D services. We have provided an explanation for this behavior which is based on the notion that the government often has imperfect information about the ability of various firms to perform R&D and similar contracts involving great technical uncertainty. In these situations, the government sponsors design and technical competitions, which may be interpreted as solicitations to companies to signal their ability to provide services and products. Signaling requires considerable R&D investment, which must be at least partially at firms' own expense for the signal to be informative.

Estimation of variants of an econometric model of company-sponsored R&D expenditure enabled us to both test the hypothesis of, and estimate the quantity of, private investment in signaling R&D. Our estimates imply that there is about 50 cents worth of private, procurement-related ("contract-seeking") R&D for every dollar of contract R&D. The amount of private procurement- (largely defense-) related R&D expenditure appears to be substantially greater than the reported costs incurred by contractors under the IR&D program. We estimate that in 1979 -- before the major defense buildup had begun -- about 20 percent of private R&D investment was induced by (related to) federal procurement. Nearly half of the increase in company R&D expenditure between 1979 and 1984, during which time federal national defense purchases grew much more rapidly than nondefense demand, was stimulated by growth in government sales. By 1984, government-sales-induced R&D accounted for about 30 percent of private R&D spending.

According to the official government statistics, the fraction of the nation's total R&D (company- plus government-sponsored) investment devoted to military research increased from 23 percent in 1979 to 30 percent in 1984. Treating all of the private R&D investment we have estimated to be associated with procurement as military R&D would increase this share to 32 percent in 1979 and 45 percent in 1984. While this procedure may result in some overstatement of the defense share of R&D, these estimates are, we think, much closer to the truth than the official estimates. The latter appear to substantially overstate U.S. investment in R&D relevant to meeting the challenge posed by competitors in the civilian technology race (e.g., Japan, less than one percent of whose R&D is military), and to understate investment devoted to meeting the challenge posed by our major competitor (the Soviet Union) in the military technology race.

# References


Bound, John, et al. (1984), "Who does R&D and who patents?" in Z. Griliches (ed.), R&D, patents, and productivity (Chicago: University of Chicago Press).

Danhof, Charles H. (1968), Government Contracting and Technical Change (Washington: Brookings Institition)

Department of Defense (1985), Prime Contract Awards, Fiscal Year 1984 (Washington, D.C.: U.S. Government Printing Office).

Fox, Ronald (1974), Arming America: how the U.S. buys weapons (Boston: Harvard Business School Division of Research).

Gorgol, John (1972), The military-industrial firm: a practical theory and model (New York: Praeger Publishers).

Griliches, Zvi (1984), "Data problems in econometrics," NBER Technical Working Paper No. 39, July.

Hausman, Jerry (1978), "Specification tests in econometrics," Econometrica, vol. 46, no. 6, pp. 1251-1271.

Kamien, M., and N. Schwartz (1982), Market structure and innovation (Cambridge: Cambridge University Press).

Kihlstrom, Richard E., and Michael H. Riordan (1984), "Advertising as a signal," Journal of Political Economy, vol. 92, no. 3, pp. 427-450.

Lichtenberg, Frank R. (1985), "Assessing the impact of federal industrial R&D expenditure on private R&D activity," paper presented to the National Academies of Sciences/Engineering workshop on The Federal Role in Research and Development, Washington, D.C., November 21-22.

Mairesse, Jacques, and Alan Siu (1984), "An extended accelerator model of R&D and physical investment," in Z. Griliches (ed.), R&D, patents, and productivity (Chicago: University of Chicago Press).

National Science Board (1983), Science indicators/the 1985 report (Washington,D.C.).

National Science Foundation, Research and development in industry, various years.

New York Times (1986), "7 Competing to Build Fighter," February 20.

Reppy, J. (1977), "Defense department payments for 'company-financed' R&D," Research Policy 6, pp. 396-410.