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PRIVATIZING PUBLIC RESEARCH:

THE NEW COMPETITIVENESS STRATEGY

by Linda R. Cohen and Roger G. Noll*

Beginning in the late 1980s, the U.S. government initiated significant changes in the fundamental purpose and structure of federal research and development (R&D) policies. Since World War II, the dominant theme in federal R&D has been national security. Over half of the federal R&D budget was devoted to advancements in defense technology. Much of the rest -- including fundamental research in mathematics and physical sciences -- was supported because of its historical connection and potential relevance to national security. But the end of the Cold War has weakened national security as the basis of political support for federal research policies. The emerging new theme, intended to substitute for the military security rationale, is international competitiveness. Its proponents argue that the federal government should support R&D to increase productivity in trade-sensitive segments of American industry to assist business in global economic competition and hence provide "economic security" for the nation.

The present efforts to change the basic rationale for R&D policy come at a time when possibilities for major new spending initiatives for discretionary programs appear remote. During the 1980s, the increasing proportion of the population that is elderly and the rising costs of publicly financed medical care shifted budget priorities in favor of entitlement programs and away from most forms of domestic discretionary spending. For most of this period,[1] federal support for R&D fared relatively well, as the Cold War arms race formed the basis for a strong defense/research coalition. As a result, the fraction of the federal discretionary budget accounted for by R&D programs continued to grow until only a few years ago.

In the late 1980s, congress adopted institutional changes that were intended to impose budgetary discipline, the most recent of which was the budget agreement between congress and President Clinton in 1993 to cap discretionary expenditures at approximately the fiscal 1993 level in nominal (not inflation-adjusted) dollars. Initially, the primary effect of tighter budget controls was on defense expenditures; however, by fiscal 1994 the defense budget had been cut by as much as either congress or the president believed was prudent.

Consequently, the cap on total expenditures, in the teeth of ever higher expenditures on entitlement programs, has caused much larger reductions in discretionary programs than in the previous decade. After their rapid growth in the 1980s, R&D programs have become an obvious target, for they account for about one-eighth of total discretionary spending (Table 1).

The aggregate data indicate that political support for federal R&D effort is beginning to unravel. One important indicator is the decline in the fraction of gross national product that is accounted for by R&D expenditures (Figure 1). Real R&D expenditures (corrected for inflation) by the federal government have fallen since 1987 (Figure 2). Real R&D in the private sector is still increasing, but its growth has fallen below the rate of increase in real output. Because a substantial fraction of private R&D is directed at defense technologies, the fall in private R&D as a fraction of output is at least partially due to cuts in defense spending.

Thusfar, the new competitiveness rationale has led to a few new programs, and succeeded in reducing the budget cuts of a few more; however, it has not offset the decline in total R&D spending. For fiscal 1994, President Clinton initially proposed an increase in federal R&D budget authority that would have matched inflation; however, congress cut the president's request by $4.4 billion, mostly for the purpose of providing more funds for other domestic programs than the president had requested (a small amount of the cut was transferred to disaster relief after the January 1994 Northridge earthquake). The actual budget outcome was a cut of $1.9 billion in nominal dollars from the fiscal 1993 budget and of over five percent in real dollars.[2] For fiscal 1995, the president has given up the quest for a significant increase in the R&D budget, having proposed only a modest 0.5 percent real increase; however, as in the previous year, the administration's target is the most optimistic possible outcome.

Recent budget trends give rise to a serious question as to whether the new rationale is an effective substitute for the Cold War in forming the basis for a durable support coalition for federal research programs and R&D budgets that equal the federal R&D effort in the preceding twenty years. On the basis of our analysis of trends in federal R&D spending, the economic case for the new programs, and the base of political support for programs based upon the competitiveness rationale, we are pessimistic about these initiatives. In particular, we foresee three major problems: (1) in some cases the government is pursuing projects with gloomy prospects for a significant economic payoff; (2) the new rationale, even if successful, is very likely to cause a significant reduction in more fundamental, long-term research and to weaken significantly one of the few remaining strengths in the American educational system, the research university; and (3) the political coalition supporting federal R&D programs is fragile, and likely to weaken as some questionable projects fail and other successful ones create powerful enemies because, by succeeding, they will create losers as well as winners. Hence, we conclude that the competitiveness rationale will not succeed in maintaining a quantity and quality of national R&D effort that compares to the levels of the past thirty years.

I. The New Competitiveness Rationale

The new theme in federal research programs, intended to be the basis for reversing the decline in R&D effort, is a broad-based policy to assist business in developing technologies that will make U.S. industry more competitive in international markets. An illustration of the new argument is the following description of AMTEX, the new government-industry partnership for commercial R&D in the textile industry:

> This industry currently provides 12 percent of all manufacturing jobs in the U.S. (including 176,000 in California). In recent times, however, imports have been replacing domestic goods at an alarming rate with commensurate loss of jobs. The purpose of the AMTEX partnership is to develop high technology that can successfully compete with cheap foreign labor. This will not only save thousands of jobs but should also generate thousands of new jobs.[3]

At the most fundamental level, the competitiveness theme as expressed in this quotation is economically irrational. As many economists have observed, most notably Paul Krugman, increased productivity is valuable regardless of whether the commodity in question is traded internationally, and is not valuable in an industry in which, regardless of feasible productivity growth, wages will remain low and costs will remain higher than the costs of imports. Reallocating R&D away from its most productive applications on the basis of the importance of the product in US trade will almost always reduce national welfare, and the rhetoric for such expenditures reveals a gross misunderstanding of the economic causes and consequences of international trade. As a case in point, the textile R&D program seems motivated primarily by the possibility that the North American Free Trade Agreement will cause a reallocation of U.S. employment away from textiles and into products in which the U.S. is a relatively more efficient producer. In fact, a textile R&D subsidy only makes sense if the net effect of this investment is to increase U.S. national product, which will not be the case if all that it does is achieve its stated objective: to make U.S. textile manufacturing costs equal manufacturing costs in Mexico and other developing countries.

The competitiveness rationale for R&D programs is new, but many recent initiatives have their roots in activities having a more defensible economic rationale that were begun during the Carter Administration.[4] At that time, concerns with flagging industrial productivity in the United States led to the Domestic Policy Review, a broad-based effort undertaken by Congress and the Commerce Department that led to several major pieces of legislation: the Bayh-Dole Act of 1980, which liberalized patent policies for inventions arising from federal grants and contracts; the Stevenson-Wydler Act of 1980, which provided a legislative basis for redirecting federal laboratory activities towards a more commercial focus; and proposals for changes in tax and antitrust policies that led eventually to the National Cooperative Research Act of 1984 (relaxing antitrust enforcement for research joint ventures) and the Research and Development Tax Credit, initiated in 1982.[5]

These policies reflected four propositions about commercial R&D policy, which are incorporated in the new programs as well. First, private control of research results (that is, privately-owned intellectual property rights) yields greater incentives to innovate and commercialize research results. Second, efficient technical choices for commercial products requires that private participants, rather than government managers, strongly influence technical choices. Third, cooperation among businesses can provide a basis for the efficient conduct of research activities but requires encouragement by government. Fourth, government resources -- most importantly the laboratories and publicly supported universities -- can play an important role in developing technology primarily for private use, rather than accidentally yielding commercial applications as essentially serendipitous spinoffs from government missions.

Although President Carter proposed federal programs to accomplish these structural reforms, his proposals led to virtually no changes in federal R&D priorities or budgetary allocations. Whereas Carter succeeded in obtaining appropriations for many specific R&D projects, these programs were aimed at matters of traditional national concern (defense and energy). His more universal proposals, justified as weapons to attack stagflation by reversing the decline in productivity growth, did not produce new spending programs. Recently, the end of the Cold War and the new competitiveness theme (although a less defensible rationale for federal spending) have provided the impetus to back up a broader commercial R&D policy with well-financed programs, despite a decline in total federal R&D spending.

Several features of the new environment have contributed to wider acceptance of these programs. The downsizing of the defense effort led the federal laboratories to search for a new role, and actively to market their research expertise for the purpose of assisting in the development of commercial products and to emphasize their value to the U.S. economy under the "technology transfer" rubric. Reductions in the defense budget gave rise to new R&D expenditures for developing technologies that would serve a "dual use" in that products used for national security purposes would be created in part out of the same parts used in related civilian products. Furthermore, the goal of supporting effective competition with foreign firms through technological preeminence led logically to privatizing research results emanating from federally financed projects, rather than leaving technical innovations in the public sector where they are more accessible for exploitation by foreign firms. Finally, the increased penetration of foreign firms into U.S. markets has led to a shift in attitudes about the importance of an anticompetitive downside to collaboration among domestic firms.

Although the actual size of all of the programs that emphasize this theme has not been published by the government, from congressional and executive branch budget documents we estimate that in fiscal 1994 at least $3 billion was spent in one way or another to subsidize private R&D consortia, with plans announced by the Clinton Administration to double or even triple this amount in three years. Thus, based on the data in Table 1, these programs already account for about ten percent of federal support for civilian R&D, are scheduled to grow to perhaps one-third in a few years, and are the only component of federal R&D expenditures that is experiencing significant growth. Moreover, because less than 2 percent of industrial R&D involves interfirm collaboration,[6] these programs already constitute more than a doubling of industrial consortia, with the prospect of accounting for an order-of-magnitude increase within a few years.

Some Prominent Examples of the New Approach

One form that the new approach can take is exemplified by SEMATECH, a consortium of semiconductor manufacturing firms that receives an annual subsidy of about $100 million. Projects are chosen by a board composed of SEMATECH members with a representative from the Advanced Research Projects Agency and SEMI-Sematech, an association of equipment and supplier manufacturers.[7] The Department of Defense also plans a similar distancing of subsidies from federal management in its new program to support the development of flat-plate displays, whereby a firm or production consortium can qualify for a matching grant for its R&D by winning a procurement contract and building new production capacity. These projects represent the extreme in delegation of management from government to private R&D performers.

A more common approach to program management, with somewhat greater government involvement in the choice of projects, is represented by the Advanced Technology Program, run by the National Institutes of Standards and Technology (NIST) in the Department of Commerce. In this approach, program management is similar to the traditional operation of the basic research programs in the National Science Foundation. Organizations seeking support submit detailed proposals to NIST, which subjects them to technical reviews and makes awards for projects that are judged to be most promising. Although proposals are solicited from all industries, nearly all projects to date have been from "high-tech" industries, such as microelectronics, superconducting materials, and biotechnology.[8]

ATP was authorized in the 1988 Omnibus Trade and Competitiveness Act and received its first appropriation, for $10 million, in the fiscal year (FY) 1990. ATP is one of the fastest-growing programs in the federal government. Its budget increased from $68 million in FY 1993 to $200 million in FY 1994. President Clinton has requested over $400 million for the program for FY 1995, and advocates expanding ATP to $750 million annually by FY 1997. Thusfar, congress has gone along with the president and is enthusiastic about it. With the increase in its budget, NIST has taken a more active role in defining the technologies that it will support, and plans to allocate most of its budget to a handful of program areas, while continuing to leave the design and supervision of the projects to private firms. ATP requires cost-matching by industry. Furthermore, the organization receiving a grant, or the lead entity in a consortium, must be a for-profit U.S. company.

The efforts to redirect defense-related R&D programs follow a similar structure. Most prominent of these is the Technology Reinvestment Program (TRP), administered by the Advanced Research Projects Agency (ARPA), the successor agency in the Defense Department to DARPA. TRP received $472 million in FY 1993, and $575 million for FY 1994. Half of TRP's budget goes to developing "dual use" technologies for both defense and civilian applications.[9] TRP also awards funds in its "deployment category" for technology transfer and engineering education. In the former category, many of the projects involve government laboratories and the manufacturing extension services run by state agencies and NIST. For engineering education, the grants have favored joint programs by engineering schools, community colleges, and manufacturing firms, and have focussed on retraining private defense industry employees. Like ATP, all TRP projects require 50% cost-sharing by participants. About a third of the budget is restricted to "eligible firms" -- commercial enterprises that conduct significant research and manufacturing activities within the United States (some foreign-owned firms can qualify).

Initially, the TRP program has proved to be almost embarrassingly popular with industry, for in 1994 proposals were submitted for a total of $8.5 billion in project costs. If ARPA paid 50% of the costs of these projects, as envisioned by TRP, this amounts to over 8 times the agency's budget. Because of its size, the dearth of alternative pork-barreling opportunities in the federal budget, and the low success rate of proposals, the program has attracted criticism as exhibiting political favoritism. Over a fourth of the fiscal 1994 TRP budget was "earmarked" during the appropriations markup in congress. Although the program's authorization requires all funds to be allocated competitively, the committee report accompanying the appropriations bill designated a list of projects, many in California, that the agency was required to support. The head of the program succeeded in inducing congress to rescind the earmarked provisions of the appropriations bill by supporting these projects out of other funds,[10] and claimed that "no credit was given [to proposals] for proximity to a seismic structure with a Spanish surname."[11]

Extra credit aside, three factors conspired to concentrate the initial set of TRP awards in California. First, the program has an explicit dual-use purpose, and California contains a disproportionate share of defense manufacturing. Second, the program favors consortia and hence, especially in the initial round, firms with preexisting collaborative efforts. Established defense contractors have unusually great experience with collaboration because of the proclivity for subcontracting in the defense sector. Third, the application and financial reporting requirements are least onerous for firms (and universities) that have substantial experience with government contracting procedures. Consequently, the development awards favor defense contractors and subcontractors, many of whom are indeed located in seismically active parts of the country.

The other major new federal effort is the Cooperative Research and Development Agreement (CRADA) program, whereby a federal laboratory engages in collaborative commercial R&D projects with one or more companies. NASA and the Department of Agriculture have longstanding authority to enter into such contracts; this authority was expanded to other agencies and almost all types of labs by the 1980 Stevenson-Wydler Act and its subsequent amendments in 1986 and 1989. CRADAs increased dramatically in 1990, when the Department of Energy's contractor-operated labs were allowed to enter into such agreements. Several thousand CRADAs are now in effect, led by the DOE and NIH labs, with NIST, the defense agencies, and NASA accounting for a substantial number of projects as well.[12]

While many CRADAs focus on rather narrow projects, some are designed to develop an entire new technology base for an industry. One example is the National Battery Consortium, which seeks to improve the prospect for an economically attractive electric vehicle. Another is the program to develop a more fuel efficient automobile, a billion-dollar collaborative effort with automobile manufacturers that has been dubbed the "swords into fenders" program. Still a third is AMTEX, the textile consortium involving several national laboratories. As with ATP, CRADA projects are proprietary, and the legislation allows for (and encourages) patent ownership by private participants. Moreover, these proprietary products can be extensions and applications of purely governmental research initiatives. An example is a CRADA involving Amgen, the genetic engineering company, in which a discovery by a scientist at Lawrence Berkeley Laboratory about the biochemical process that triggers growth of tendon cells is being developed into a commercial product at a cost of only $1.8 million (25 percent paid by the Department of Energy) that will be the property of Amgen.[13]

The cost of CRADAs is difficult to ascertain because the government's contribution of shared lab facilities and personnel is not separately budgeted. Nevertheless, the program is comparable in importance to ARPA and ATP. For example, in FY 1994, the federal government is estimated to be spending $350 million for CRADAs at Department of Energy laboratories, and another $135 million on cooperative ventures at NASA labs.[14] President Clinton has proposed allocating ten to twenty percent of the DOE lab budget, along with significant shares for other agencies, to CRADAs.[15] The nation's 700 laboratories spend about $25 billion annually (over 30% of federal R&D), so that CRADAs could grow to several billion dollars in federal spending if the labs succeed in finding private firms willing to share costs.

Universities in the New System

The new policy has produced changes even at universities. Historically, universities have performed about half of the basic research conducted in the United States (Table 2). Since 1980, the government has allowed universities to patent the results of research performed under federal grants and, with a few exceptions, to sign exclusive licensing agreements with domestic manufacturing firms.[16] The effect has been dramatic: the income of major research universities from patent royalties has increased a hundred fold since the early 1980s. In addition, federally sponsored research at universities increasingly emphasizes commercial applications and cost sharing. For example, the Engineering Research Centers Program in the National Science Foundation provides federal grants to projects undertaken with the collaboration of private businesses. NSF is under pressure from Congress to support more applied research; in the FY 1994 budget, congress required that NSF allocate 60% of its budget for supporting "strategic projects," a poorly-defined concept generally thought to involve near-term economic payoffs.

The new commercialization initiative is having a significant effect on the pattern of support for universities.[17] During most of the 1980s, the real research budgets of universities grew dramatically, with rapid rates of growth from all sources. Since 1988, this growth has slowed substantially, especially from federal support. Although real federal expenditures for university research grew by approximately 3 percent per year between 1988 and 1993, this growth was only about half the rate for the previous five years, and as a result the share of university R&D that is supported by the federal government fell from 61% to 56%. The decline is dramatic when compared to the high-water mark for the federal share of university research support: 74% in 1966. Over the past twenty years, the share of university research that NSF classifies as "basic" fell from 77% to 64%, while the share of "applied" research rose from 23% to 36%. The federal share of university research has now returned to the share that existed in the pre-Sputnik era, although the levels, of course, differ enormously. In 1958, the federal government paid for 56% of university research, and 62% of university research was basic while 38% was applied.

II. The Economic Foundation of the New Rationale

The link between technological innovation and productivity has a firm foundation in theoretical and empirical research in economics. A rich line of research, including work by Moses Abramovitz (1956), Robert Solow (1957), Edward Denison (1985), Zvi Griliches (1984), Richard Nelson (1964), F. M. Scherer (1984), and many others, concludes that more than half of the historical growth in per capita income in the U.S. is due to advances in knowledge, and that the total economic return to investment in R&D is several times as high as the return to other forms of investment. (Lawrence Lau's chapter in this volume reports an important new advance in this line of research.)

The fact that R&D is an important source of improvements in economic welfare is not, by itself, sufficient reason to justify a major role for the federal government in financing it. Nevertheless, here as well economics research has developed a rationale for government subsidies of R&D. Although research on the issue has produced widely differing estimates of the distribution of the economic benefits of technological change, the consensus view is that most of the benefits of innovation do not accrue to innovators, but to consumers through cheaper and/or better products and to workers in higher wages arising from higher labor productivity.[18] Because the benefits of technological progress are broadly shared, innovators lack the financial incentive to engage in as much investment in improved technology as is socially desirable. Profit-oriented businesses can be expected to evaluate R&D projects on the basis of their private profitability, not total social benefits, so that businesses are not likely to pursue some projects that produce significant benefits to consumers and labor. As a result, from a societal perspective, business will underinvest in R&D.

More recently, a second rationale for public R&D policies has emerged in the economics literature, following a line of argument developed by, among others, Richard Nelson and Sidney Winter (1982), and Nathan Rosenberg (1976). (Nathan Rosenberg's contribution to this volume follows this tradition.) This view flows from three observations about the process by which businesses identify and develop potentially beneficial new technology. One observation pertains to the uncertain process by which scientific knowledge is assembled into new technologies. A technical innovation typically embodies many advances in knowledge, some of which arose from solutions to seemingly unrelated problems and which were completely unanticipated by the original researchers and their sponsors. A researcher may not know all the promising uses of a new advancement in knowledge, and a research manager may be unaware of technical information that would be very useful to an ongoing project. The second observation is that R&D is not best conceptualized as a unidirectional flow (the "pipeline" model) from basic to applied to developmental research, but instead as a mutually interactive process in which potentially useful ideas about any one stage of the R&D process can emerge at any other stage (the "chain link" model).[19] The third observation is that the cost of transferring knowledge from one project to another is likely to be lower among researchers who work in teams or at the same location than among researchers who are physically and organizationally separated.

An important implication of these observations is that R&D is likely to exhibit economies of scale and scope -- that is, a given R&D expenditure is likely to produce a greater return in terms of advancement in technology if it is performed in the same organization rather than divided among several. Moreover, these economies are especially likely to occur at the earlier stages of innovation, when a new technology is being designed and the details of its application are being worked out. Of course, these economies can be offset by organizational diseconomies and greater risk-aversion in large corporations.

The significance of these observations for policy hinge on possible conflicts between efficiency in conducting R&D and protecting proprietary information. A collaborative R&D venture among companies with overlapping but in some ways distinct technical capabilities and knowledge can increase the productivity of research because it reduces the costs of learning about and transmitting new technical information while reducing the organizational diseconomies associated with large firms; however, for parallel reasons a firm that participates in a research collaboration will be less likely to protect its own valuable proprietary knowledge, and so risks losing some of the appropriability of its own research. The latter factor then leads to underinvestment in collaborative efforts.

III. Policies to Increase Commercial R&D

In principle, government can solve the problem of underinvestment in R&D in two ways: by increasing the profits of innovators, or by undertaking R&D in areas where the private sector underinvests.

Making Innovation More Profitable

The first approach to R&D policy, which tends to be emphasized by political conservatives, is accomplished by making intellectual property rights more secure, by providing tax subsidies to innovative activity (such as the R&D tax credit), or by permitting, or even encouraging, mergers and acquisitions of horizontal competitors when the combined entity is likely to be more effective in research. In the last case, greater appropriability is obtained by creating concentrated or cartelized industries.

Historically, the most important policy has been to protect intellectual property rights: patents, copyrights, and trade secrets. More secure intellectual property rights increase the incentive to innovate, but they also have three major drawbacks.[20] First, intellectual property rights increase profits by establishing monopolies, and thus lead to economic inefficiency due to excessive prices and restricted production. Second, in some cases intellectual property rights can inhibit follow-on innovations by others who combine an older technology with a new idea. Extreme privatization of information can prevent one entity from understanding the technology invented by another well enough to recognize a useful extension of it. And when two holders of potentially compatible intellectual properties are aware of each other's technology but each is uncertain about their combined value, the firms can fail to reach an agreement to collaborate even when collaboration is beneficial to both. Third, intellectual property rights limit diffusion of research results. Because research can have applications in many products and industries, its potential benefits are realized only if results are diffused broadly and other companies have an incentive to find new applications for them. The fact that diffusion costs are higher across than within organizations does not imply that interorganizational diffusion is not important in the innovative process and so can be safely ignored without disadvantageous consequences. For these reasons, the economically optimal system of intellectual property rights is not one which maximizes the extent to which all commercially relevant technical information is durably protected.

Tax policies have the virtue of simplicity, but they present problems as well. One problem is the accounting and auditing costs associated with monitoring compliance with the tax code. Tax subsidies increase tax complexity, and thereby the collection costs of the tax system. Another problem is that tax subsidies can not easily be constructed to be focused on the R&D activities that produce the largest spillover benefits and that suffer the greatest underinvestment by the private sector. In fact, tax subsidies do not alter the fundamental incentive of private industry, which is to invest in technologies that generate the greatest private profit, as contrasted to the highest social return.

Policies to encourage significant concentration of research-intensive industries have been advocated in the U.S., but with little success. The U.S. has a more vigorous antitrust policy than other advanced industrialized nations. The only change in antitrust policy regarding R&D was legislation in 1984 that reduced the exposure of firms collaborating on R&D from triple to single damages if their collaboration is first registered with the government. Whereas several hundred collaborations have been registered since the act was passed, the importance of this change is debatable because antitrust complaints focusing on research collaborations were exceedingly rare before the change was made. In fact, approximately two-thirds of the antitrust registrations have involved three industries in which research-related antitrust concerns have been raised in the past: the telecommunications industry (the various divested components of the old AT&T have filed numerous registrations), the computer industry (the old antitrust suit against IBM contained allegations regarding IBM's research policies), and the automobile industry (in the 1960s, the Big Three undertook a collaborative program to invent methods to reduce emissions from autos that was later alleged to have been an industry-wide conspiracy to slow down the rate of technological progress in this area).[21]

Targeted Correction of Market Failures

The second type of solution to the problem of underinvestment in R&D, which tends to be emphasized by political liberals, is for the government to subsidize it through grants for specific projects. In this case, the government selects specific technologies and areas of basic research to support, either subsidizes them in the private sector or undertakes them in government research laboratories, and then attempts to disseminate the new technologies by making the research results freely available to anyone who can make use of them.

Subsidization policies have drawbacks as well. One source of problems is the effect of subsidies on the incentives of those undertaking the research. Without the opportunity to profit from applications, researchers may not pursue topics that have the greatest potential economic payoff, and may be prone to make promises that government officials want to hear, rather than that are based on a sober assessment of technical and market realities.

Another drawback of subsidization policies is the system of federal procurement. The federal government's methods for procurement of products that are not widely available in the private market are extremely detailed, complex, and inflexible, leading to an inordinately large administrative cost in managing federal contracts and great difficulty in redirecting effort as one proceeds in fulfilling a contract. Whereas this tendency for elaborate and costly contractual arrangements may well reflect general public skepticism about the propensity of government to be wasteful and corrupt, and the concomitant political payoff to elected officials who uncover scandals and punish the perpetrators, the problem is deeply rooted in the nature of a broad class of procurement activities, including R&D projects.

Efficient contracts for technology development across organizational boundaries are especially difficult to write, which is why private firms virtually never attempt to procure R&D from other organizations rather than to undertake it in house. The cause of the problem is uncertainty about both the costs and results of R&D, which must be imperfectly known or else the research would not have to be undertaken in the first place. Because of this uncertainty, the government faces difficulties in specifying realistic technical approaches and objectives, and in monitoring the performance of the contract. Moreover, as work proceeds, the government is quite likely to change its mind about the kind of product it wants, based on new information that arises in the early stages of a project. Consequently, R&D contracts usually are based on some form of cost-reimbursement formula, despite the notorious tendency of such contracts to produce cost overruns.[22]

Because whether a contractor is putting forth best effort and managing a project wisely is extremely difficult to detect, the government's traditional solution to the contracting problem is to impose elaborate cost-accounting and audit requirements on R&D contractors, and to put forth great effort to find even a tiny amount of waste, fraud, or lax management. This system of monitoring is far more complex, costly, and inflexible than the monitoring systems that are used in private organizations for conducting their own research, and as a result, R&D undertaken under federal contract is inherently more costly and less effective than R&D undertaken with internal funds. Indeed, federal contractors for R&D and other sole-source products often engage in "walling off" the government work -- that is, they carry out private activities in separate facilities, using separate employees and an entirely different management and accounting system, to make sure that the rigidities and monitoring expenses of the federal activities do not carry over into the private work.[23]

A third source of problems with subsidization policies is that the government may not be very adept at picking promising technologies, particularly if the goal is a commercial product rather than one that supports a government mission, and in any case is prone to allocate funds according to political criteria rather than strictly the technical and economic merit of a proposal.[24] Because technical information is difficult and costly to transmit across organizational lines, federal officials are likely to know less about technical opportunities, market requirements, and a contractor's capabilities than the contractor knows. Because federal sponsors are trying to cure a market failure by inducing contractors to pursue projects that they have insufficient private incentive to undertake, a contracting agency faces a fundamental dilemma: is the contractor's reluctance to pursue the agency's plans without modification based on the contractor's superior knowledge, or the result of the incentive operating upon the contractor to bend the project more towards activities that promise greater appropriability of the research outputs and so higher long-run profits for the contractor?

A fourth source of problems with the subsidization policies is adverse political incentives for maintaining an efficient portfolio of commercially-oriented projects. The portfolio problem arises from two distortions caused by political control. First, historically the government has had extraordinary difficulty in abandoning large development projects that were clearly failing efficiency tests. Unfortunately, technical and economic failure does not necessarily lead to the timely demise of a government program, for, unlike the private sector, government officials are sensitive to the effects of project cancellation on employment at the facility and profits of contractors. Alternatively, some projects that are successful run into another problem: they are perceived as unfair by nonparticipating firms on the grounds that the government is determining the pattern of success and failure among companies in the industry.[25] In brief, the government is probe to abandoning worthwhile projects while continuing poor ones -- so that even if it were as adept at industry in picking worthwhile projects initially, its portfolio of projects overall would tend to be weaker.

The Role of the Two Strategies: History and the New Rationale

Historically, the two basic approaches to R&D policy -- measures to increase the profits of innovators, and subsidies of specific types of R&D to offset private underinvestment -- have been regarded as substitutes. Technologies in which private industry could hold a reasonably secure intellectual property right were expected to be supported by business. Government supported this private R&D only indirectly, through preferential tax treatment, the system of intellectual property rights, and grants for fundamental research at universities and national labs that was available to the private sector for free -- if businesses could figure out where to look. Government also supported some developmental R&D, but argued that it did so only when the benefits were likely to be widely dispersed. In all cases, the government insisted that the results of its projects be disseminated. Even in defense technologies, where national security considerations led officials to retain maximal confidentiality about some research results, the government frequently called upon one contractor to produce technologies that were developed by another, encouraged (and sometimes required) defense firms to disseminate firm-specific technical knowledge through subcontracting, and welcomed commercial adoption of technologies that were not closely related to highly confidential defense products, such as advances in computers, microelectronics, and telecommunications.

The use of direct federal subsidies of commercially relevant R&D is more than a hundred years old, having supported the development of the telegraph and hybrid seeds in the 19th Century. Nevertheless, direct federal support of R&D did not become a significant component of national R&D effort until World War II, and even then it was confined almost exclusively to defense-related technologies. Not until the 1960s did the federal government undertake a broad array of research programs for primarily civilian purposes, at that time initiating important new programs in biomedical technology, supersonic commercial aircraft, and geosynchronous communications satellites, and smaller programs in several other areas, including synthetic fuels from coal, environmentally benign automobile engines, and new construction methods.

Even after the new initiatives of the 1960s, the federal government lacked anything remotely resembling a coherent, economy-wide strategy for civilian R&D. The majority of federal R&D dollars were still spent on defense or fundamental knowledge that was relevant to defense, and the remaining civilian programs were a series of largely unrelated, targeted responses to much narrower public issues than the overall long-run performance of the economy. Examples were the War on Cancer, the desire for more environmentally benign production methods and products, the perceived threat to the national preeminence of the U.S. aircraft industry after defense aerospace technologies significantly diverged from commercial technologies, the persistent decline of the eastern coal-mining industry, and, in the 1970s, the search for an effective technological response to the rise of the worldwide oil cartel.

By contrast, the new approach is essentially economy-wide, and owes its appeal both to productivity justifications and to the common belief that the dominance of international markets by U.S. manufacturers can be reclaimed (or strengthened) through innovation. The new approach rejects the prior view that policies to make commercially relevant technical knowledge more proprietary are alternatives to direct federal support. Proponents of the new theme argue that by making the products of federally supported research the property of the private entity that undertakes it, research organizations will have a greater incentive to bring new technical knowledge to commercial practice. Moreover, foreign companies will face greater costs and delays in trying to make use of the products of this research, giving American firms a competitive edge in international markets. Proponents buttress their case by pointing to the similar approach to R&D undertaken in Japan (computers and microelectronics) and Europe (Airbus), where governments have created and subsidized collaborative, proprietary R&D projects in the private sector that have led to important gains in the international market shares of domestic industries.

The combination of a proactive role in selecting and paying for commercial R&D and giving proprietary rights in research products to private industry has appeal to both conservatives and liberals, and so, like defense prior to the demise of the Soviet Union, can command bipartisan political support. This advantage is exemplified by the fact that the Clinton Administration's R&D policy is primarily a continuation and expansion of the R&D policy of the Bush Administration, which in turn has roots in the Carter policy and attained budgetary significance through relatively nonconflictual collaboration with a Democratic congress.

IV. Economics, Politics, and the Future of the New Strategy

Despite its advantages, there are good reasons to believe that the new approach to U.S. R&D policy will not succeed either economically or politically. Because the political problems are rooted in the economic consequences of the policy, it is useful to begin by examining the economics of the new theme.

Fundamental Research and Privatization of Knowledge

An important economic consequence of encouraging privatization of knowledge is that it works far better at encouraging the more developmental end of research than at encouraging more fundamental advances in knowledge. The U.S. system of R&D is unique in the role it assigns to universities in performing basic research. The historical U.S. policy of supporting university research and encouraging open and free dissemination of the results not only accommodates diffusion of research across organizations, but it also permits an integration of teaching and research that is uncommon elsewhere and that facilitates the diffusion of new knowledge to industry through students. Even basic research at national laboratories has been carried out in a similar fashion because many labs are managed by universities, and most have numerous faculty and students in residence undertaking experiments.

Economics research indicates that the economic payoff to basic research is higher in the U.S. than in other nations, and the most plausible cause is unique American emphasis on research universities.[26] Making the dissemination of basic research more difficult is likely to reduce its economic payoff to society -- albeit probably not to the university. Furthermore, research that is motivated by its profitability is far more likely to focus on projects with a predictable application, causing university research to be more applied and focused, and hence to generate less foundational knowledge with widespread application across a variety of industries.

Encouraging universities and national laboratories to make the results of their research proprietary, either by giving universities exclusive rights to the products of government-financed research or by subsidizing more extensively proprietary collaborations with industry, sets a troubling precedent for the institutional structure of basic research in the United States. Some of these changes may be inevitable. The historical generosity of government in supporting basic research apparently is no longer sustainable. Nevertheless, the new policies are not substitutes for the old, and are likely to have economic significance because the social payoff to basic research in the U.S. has been so high.

The Profit-Inducement Strategy: Property Rights and Cartelization

A very important element of the economics of privatized and collaborative research is that it can reduce competition in domestic industries. Obtaining maximum security of intellectual property rights requires eliminating market competition, which, if innovations can not be durably protected by their creators, requires domestic cartelization of industry and permanent, impermeable barriers to import competition.

Industry cartels and protectionism are far more common in Japan, the newly industrializing countries of Asia, and, to a lesser extent, Western Europe than in the United States. The post-war history of Japan illustrates especially well the dilemma inherent in this trade-off. By facilitating the formation of cartels, Japan has produced a system that ranks first in the world in the fraction of gross domestic product (GDP) that is spent on R&D and other forms of investment, that produces a higher rate of sustained economic growth than any other advanced, industrialized economy, and that has persistently low unemployment. Moreover, in Japan a far lower proportion of R&D is financed by government than in the world's other leading economies, and defense plays virtually no role in motivating public or private R&D.

The other side of Japan's remarkable performance is that the standard of living of the ordinary Japanese citizen is far below living standards in other nations with approximately the same per capita GDP. Although the average Japanese employee works substantially more hours per year than the average American worker, the real purchasing power of average annual take-home pay in Japan is approximately 75 percent of the real value of the average American's take-home earnings -- a remarkable fact considering that the real value of wages for average American workers essentially has not increased for twenty years. Moreover, many Japanese are not pleased with their own economic system. The recent political upheaval in Japan, while sparked by scandals among members of the ruling party, has been brewing for more than a decade, and was rooted in the increasing dissatisfaction engendered by the inability of the ordinary Japanese to attain a standard of living that is roughly equal to living standards in North America and Western Europe.[27] A key lesson from the experience of Japan is that policies that provide especially sharp financial incentives for private investment will produce rapid economic growth, but the economic benefits of that growth will not be as widely shared.

Limits to the Economic Rationale for Promoting Collaboration

For programs subsidizing industrial R&D, the new theme for federal research is based on an incomplete conception of the incentives affecting the innovative process. A ubiquitous element of the new research policy is that the government should encourage industry-wide research consortia to pool the resources of otherwise competitive companies, perhaps by subsidizing such ventures, but also by granting antitrust immunity to them. But industry-wide collaboration does not necessarily increase overall research effort and the rate of technological progress.

Whether collaboration is beneficial depends on the details regarding the nature of the work that is undertaken and the role of domestic industry in the international economic system. R&D collaboration among domestic competitors is unlikely to produce the undesirable effects of a domestic cartel in either of two circumstances. First, if trade in the products of the industry is free and several nations are efficient producers, even a complete merger of all domestic companies will create simply another competitor in the world market. In this case, domestic collaboration can be beneficial if it enables the domestic industry to capture scale economies in R&D, to exchange specialized expertise across companies, or to avoid duplicative research. Second, a collaboration is likely to be beneficial if it is limited in scope to expanding the technological base of the domestic industry, enabling each firm in an industry to make use of this research to develop its own proprietary products. In this case, collaboration in more fundamental research does not inhibit domestic competition among the collaborators.

Centralized "technology base" research is likely to be beneficial across a wide spectrum of industries. Unfortunately, changes in the technology base of an industry typically are difficult to protect with intellectual property rights. Consequently, such programs are unlikely to be effective in confining their new knowledge to U.S. firms. Furthermore, separate efforts by competing domestic companies to apply the new technology base will dissipate the private profitability of the technology-base research. Thus, industry-wide technology-base programs, while attractive as an efficient means to develop new technology, are neither very effective as part of a national competitiveness strategy nor likely to generate a great deal of enthusiasm from business -- unless, as was the case in Japan, they are married to a domestic production cartel and effective trade barriers.

Industry-wide R&D programs are likely to take one of two directions. If they retain a generic technology-base focus, the public sector is likely to be called on to provide most of the financial support. This option appears unlikely in these penurious times, particularly if the project lacks strong industry support. Alternatively, industrial participants are likely to press for a reorientation towards work on more focused developmental research projects, which can be more effectively protected by patents and hence offer greater profits to the domestic industry. The problem then becomes the possibility of domestic cartelization. By contrast, research on innovation demonstrates that a large proportion of technological progress comes from new, upstart entrants or firms from outside an industry. Hence, if the national interest rests on increasing the rate of technological progress, industry-wide R&D cartels with government R&D subsidies are very likely to be counter-productive.[28]

Collaboration on applications research can be socially beneficial if the domestic industry faces competition at home from foreign producers; however, as a practical matter, centralization of domestic R&D beyond the technology base is almost always dangerous. Even when the domestic market is open to relatively free imports, poor performance by the domestic industry usually leads to trade barriers, such as the import quotas that were adopted by the U.S. for steel, autos, semiconductors, and numerous other products when the domestic industry began to lose significant market share to foreigners. Hence, industry-wide centralization of more applied R&D gives domestic consumers something of a Hobson's choice. If the venture is successful in making U.S. industry more productive than its foreign competitors, the domestic industry will retain most of the benefits of its improved productivity by cartelizing the domestic market. If the venture is unsuccessful, and the domestic industry loses market share to foreigners, import restrictions are likely to be imposed, leading again to a domestic cartel -- but in this case one that is inefficient as well as monopolistic. In either case, the main effect of centralized R&D is to transfer wealth to the domestic industry, not to improve the economic welfare of most citizens.

If centralization of applications research for an entire domestic industry is dangerous, another possibility is to support projects undertaken by one or a few firms that account for only part of the domestic industry. Supporting only some firms in an industry, especially one that has numerous but technologically differentiated firms, can be attractive because it enables the government to capture economies of scale and scope without supporting all technical ideas and creating a cumbersome decision process that accommodates a large number of players. This has been the approach taken to date by the National Institutes of Standards and Technology in its ATP program, although whether this strategy can survive a vastly expanded budget is doubtful. In principle, such a strategy can preserve technological competition among domestic companies while increasing overall R&D effort. However, in competitive industries these kinds of programs quickly run into the claims by disgruntled displaced firms that the government is unfairly helping their competitors.

Another form of the "picking winners" problem arises because of the strict policy of focusing subsidies on U.S. firms. In some of the most visible high-technology industries -- most notably, computers -- few final products are composed entirely of components from a single nation, and some research collaborations across national boundaries are already in place. For example, in the nonimpact printer industry (with $5.5 billion of U.S sales in 1989), the dominant firms are both American: Apple and Hewlett-Packard. The active optoelectronic components, accounting for less than 15 percent of the cost of these products, are mostly manufactured in Japan, although Texas Instruments is also in this business. The DRAM chips in the printer are manufactured in Japan; however, the integrated circuits that control the Japanese optoelectronic component tend to be manufactured in the U.S., mainly by Motorola.[29] A U.S. cooperative research venture in nonimpact printers that barred Japanese participation would threaten at least some U.S. firms, either the dominant printer manufacturers if they did not want to end their procurement of Japanese optoelectronics, or Motorola if manufacturers agreed to switch to the TI component.

The laser printer example demonstrates the fundamental dilemma of the competitiveness rationale, and accompanying prohibition against foreign collaboration. Specialization based on firm-specific expertise can lead to products for which the most efficient distribution of manufacturing responsibilities crosses international boundaries. Attempts to overcome these international cooperative relationships in the name of trade flows wastes R&D resources, causes a loss of sales by domestic manufacturers who efficiently use some foreign components, and increases prices to purchasers of the product by eliminating the cheapest alternative.

Problems with Public/Private Collaboration

Programs encouraging more coordination and collaboration between public and private research efforts are also likely to face significant problems. With respect to collaborations between industry and either national laboratories or universities, the main issues are the degree of interest overlap and the extent of synergistic capabilities. Certainly both exist to some degree, but the issue is whether the present plans for expanding these collaborations are consistent with the magnitude of potentially fruitful complementarities. The basic problems are that the missions of these organizations -- defense weapons development and basic scientific research -- have a limited commonality with the commercial objectives of industry. Although the Clinton Administration is a leading advocate of these collaborative efforts, its Office of Technology Assessment (1993a and 1993b) has expressed some important limitations to these programs. One report offers the following synopsis of its findings.

> "For the longer term future, R&D partnerships with industry, per se, are not likely to provide a satisfactory central mission for the weapons labs. As public institutions, the labs' existence is best justified if they serve missions that are primarily public in nature. The lab technologies that are currently exciting high interest from industry are drawn from

> the well of public missions of the past half century, especially nuclear defense. ... There is also growing interest in expansion of the labs' public missions into newly defined areas. ... However desirable they may be, it is not likely that any of these [new opportunities] would create nearly enough jobs at the right time and in the right places to compensate for the hundreds of thousands of defense jobs being lost..."[30]

The dual-use programs raise similar concerns. Here the form of the cooperative objective is different, in that the purpose is to bring greater commonality among components of defense and civilian products. The problem arises because the problem of picking the optimal point on the cost/performance trade-off can have a very different solution in defense and civilian systems. In some cases, defense accounts for a very small part of total industry output, so that an attempt to bend R&D for a dual-use technology for defense purposes could undermine the much more important position of domestic firms in the civilian part of the industry. For example, consider the potential future market of high-resolution display devices, including HDTV and flat-panel displays. Annually, over 100 million computer display terminals and television sets are produced worldwide. In the U.S., about 10 million cathode ray tubes are used for computer terminal displays, 8.9 million of which are imported. But the U.S. is a leader in the high end of cathode ray displays, producing 2.4 million and exporting 1.1 million of the most expensive versions. Another one-million flat-panel displays are sold as parts of newly manufactured laptop computers. In this market, the motivation for the defense dual-use program in this industry is an annual use of 76,000 high resolution flat-panel displays for government aircraft and 220,000 high-performance displays for computers.[31] Obviously, at this scale, there is a serious question whether it is necessary or desirable for the government to try to bend the technology of domestic display devices for dual-use purposes, and whether in the post-Cold War era the government's total funds in this area -- R&D plus procurement -- will be adequate to influence the technology should government try to do so.

The Procurement Dilemma

As discussed above, direct federal support for commercial R&D seems inevitably to lead to onerous accounting and audit processes. In fact, most of the new programs have adopted the same procedures for submitting proposals and monitoring performance that are used for defense procurement and other government R&D programs. These methods for increasing the accountability of federal recipients of grants and contracts undermine the effectiveness of federally sponsored R&D programs. The more obvious effect is on costs: the procedures for defining the details of a project, developing the substance and budget of a proposal, and monitoring progress and expenditures lead to substantially higher costs of research. Both universities of private companies, when left to their own devices, develop far less complex procedures than the government requires -- and so incur lower expenses while retaining greater flexibility in carrying out projects.

Federal procurement procedures have another undesirable effect on the overall effectiveness of R&D policy in that they create a selection bias in projects. Specifically, participation is going to be more difficult for industries that are not involved in federal procurement activities, and that would have to develop such procedures and negotiate accounting and operating agreements with the government before being eligible to participate. Some prospective recipients of support may not find it worthwhile to develop ways to adhere to required federal procedures. Even if they do develop such procedures, a likely consequence is "walling-off" federally-supported work from other research in the organization, reducing the ease of technology transfer between public and private projects.

Cutting Losses -- and Not Winners

The new programs were explicitly designed to subsidize commercial development while avoiding the "pork barrel" problems that have plagued previous large commercial R&D efforts. In particular, management choices for the programs are decentralized to a much greater degree than on previous programs, and program characteristics are intended to incorporate private incentives. As the focus of the programs is commercial development, rather than government missions, their emphasis on private selection of projects is probably wise. However, we are not sanguine that the programs can avoid the subsequent selection problems that have distorted previous government programs.

For example, the programs require cost-sharing by industry, in part to avoid continued support of failed projects. The logic of the argument is that poor projects will die when private participants bail out. This logic may work for small projects, but frequently a big project -- one with substantial employment -- becomes too important politically for the government to abandon. Instead, congress is likely to revise the program so that government assumes a greater financial burden. Some of the most celebrated federal technology turkeys, including the Clinch River Breeder Reactor and the Supersonic Transport project, started out in life with apparently iron-clad cost-sharing requirements. One wonders whether a substantial failure by ventures such as SEMATECH and the flat-plate display project would lead to the demise of the program rather than an increase in the federal financial contribution. Moreover, even the very limited experience with the new programs suggests that the claims of unfairly-subsidized successes will have equal applicability to these programs as to previous federal efforts.[32]

These arguments do not imply that government should never support a commercial R&D; instead, it means that proactive government subsidization is unlikely to prove to be an effective mechanism for enhancing productivity across a broad spectrum of industries. Moreover, it also explains the attraction to both government and industry of supporting industry-wide R&D collaboration. Because industry-wide projects do not create losers, they are unlikely to be killed because they might succeed. Furthermore, historical precedents suggest that if such a program is a technological failure, not only will information not be forthcoming that would allow the timely cancellation of the project, but that government is likely to "buy out" the private participants and continue the effort. Once again, the logic of the economics and politics of R&D programs implies a tendency towards complete centralization -- and the problems it creates.

V. What Works: Are Economics and Politics Compatible?

The preceding review of U.S. R&D policy leads inexorably to the conclusion that the U.S. has not yet found a politically viable and economically attractive solution to the problem of encouraging beneficial technological progress. Both economic research on R&D and historical experience with government programs suggest that the most effective combination of policies is likely to be a proactive program to subsidize fundamental and technology base research, partly in basic research facilities like universities and national labs and partly in collaborative centers for particular technologies, and to make the results of such research broadly available rather than proprietary. Additional incentives for applications research can be beneficial, but they are likely to be more effective if they are implemented through an indirect, broadly based program such as the R&D

tax credit. Targeted subsidies for specific commercial applications can sometimes be effective, but only if they are limited to special cases where the government as a user or producer has a major stake in the product of research (as was the case for defense) or where the technology and economic structure of the industry make the risks of cartelization minimal.

Unfortunately, this more effective approach has significant political liabilities. The benefits of such a program will accrue primarily to consumers, yet most of the active political support for R&D programs is from industry. And, because the results of technology-base programs usually cannot be confined to the entities that undertake the research, the benefits of this approach can not be confined to U.S. firms, vitiating the competitiveness rationale for the policy. Thus, the economically preferred approach from the standpoint of maximizing the growth in productivity does not respond to the sources of a political demand for domestic R&D policy. In this sense, domestic R&D policy has an interesting parallel to education policy in that, whereas there is widespread agreement that a change in policy is necessary, no effective means has been developed for mobilizing the political system to tackle the problem. In the case of R&D, until a replacement is found for national security as the consensus-creating theme, federal R&D support, especially in more fundamental areas that contribute to the technological base of industry, is likely to continue to decline, with a debilitating long-term effect on economic growth. Thusfar, historical experiences seems to provide only negative lessons: neither an appeal to the goal of enhancing overall national economic performance, as attempted by President Carter, nor the economically less attractive call to arms based on international competitiveness, as developed in the Bush and Clinton Administrations, has yet proven effective as a political rallying cry.

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FOOTNOTES

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1. To emphasize the connection between defense and government R&D, the only other period to witness a decline in federal R&D activities was during the War in Vietnam and the Nixon era detente with the Soviet Union.

2. The best source for up-to-date information about the federal R&D budget is the series of publications by the Intersociety Working Group of the AAAS, as referenced in the bibliography. The data reported here are taken from their FY1994 and FY 1995 reports.

3. Lawrence Berkeley Laboratory (1994b), p. 24.

4. See Advisory Committee on Industrial Innovation (1979) and Office of the White House Press Secretary (1979).

5. For a concise discussion of the major technology policy legislation, see Larson (1992).

6. U. S. Congressional Budget Office (1990), p. xiv.

7. for more information about Sematech, see Congressional Budget Office, (1990); Cohen and Noll (1992).

8. For a discussion of ATP program requirements and descriptions of supported projects, see National Institute of Standards and Technology (1994).

9. A description of TRP is contained in Advanced Research Projects Agency (1993). A list of FY 1994 awards can be found in *New Technology Week*, October 25, 1993; November 19, 1993; December 13, 1993; and February 28, 1994

10. See Intersociety Working Group (1994).

11. "Q&A with Lee Buchanan," in *Defense Week*, Monday, April 11, 1994, pp. 8-11.

12. Office of Technology Assessment (1993a), (1993b).

13. Lawrence Berkeley Laboratories (1994a), p. 25.

14. Intersociety Working Group (1994), p. 14.

15. Council of Economic Advisers (1994), pp. 194-204.

16. For a discussion of current university patent policies and licensing trends, see U.S. General Accounting Office (1992).

17. Data on the distribution of university R&D are taken from various issues of Science and Engineering Indicators, compiled by the National Science Foundation.

18. For an excellent survey of this research, see Griliches (1992).

19. For a detailed explanation of this idea, see Kline and Rosenberg (1986).

20. For a thorough analysis of the trade-offs involved in designing a system of intellectual property rights, see Nordhaus (1969).

21. Clearinghouse for State and Local Initiatives ... (1993).

22. For analysis of the incentive effects of procurement contracts in the development of defense weapons systems, see Demski and Magee (1992) and Rogerson (1992).

23. See Markusen and Yudken (1992) on how defense procurement rules can undermine converting defense firms to civilian production.

24. These issues are examined in the context of six major government R&D programs in Cohen and Noll (1991).

25. See Cohen and Noll (1991). A recent example was an unsuccessful attempt to block a CRADA at an EPA lab through a lawsuit. The district judge found that the plaintiff lacked standing to challenge the CRADA, because: "Nowhere in the legislative history of the Act [enabling the establishment of CRADAs] is there any indicia of a Congressional concern for the interests of individual businesses qua competitors. Rather, the Act is concerned with improving the nation as a whole so that it may compete globally, not with ensuring the competitive rights of individual companies." (*Chem Service Inc. v. EPA, et al.*, Civil Action 92-0989, U.S. District Court for the Eastern District of Pennsylvania.) Notwithstanding the legal issue, this type of program is vulnerable politically. In 1993, a highly publicized $70 million CRADA to develop supercomputing technology signed between Cray Research and two DOE laboratories was unceremoniously shelved after other domestic supercomputer manufacturers complained to congress.

26. See Griliches (1986) and Mansfield (1980, 1988).

27. For a comparison of the political context of economic policy in Japan and the United States, see Kernell (1991), especially the chapter by Shimada.

28. See Jewkes, Sawers, and Stillerman (1969) and Dorfman (1987).

29. Several examples of U.S.-foreign collaboration on high-technology products, including details about laser printers, are discussed in Congressional Budget Office (1990), Chapter III.

30. Office of Technology Assessment (1993a), p. 2-3.

31. Congressional Budget Office (1990), p. 47-50.

32. See note 25, *infra*, and the discussion of Sematech in Cohen and Noll (1992)

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The Feasibility of Effective Public-Private R&D Collaboration: The Case of CRADAs

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ABSTRACT: *Since the mid-1980s, the federal government has supported collaborative research and development in private consortia and between industry and national research laboratories. One justification for these activities is that they can solve "public goods" problems associated with producing nonappropriable, technology-base research; however, these efforts also create formidible contracting problems similar to those experienced in defense weapons systems development. We examine the early history of collaborations with the national laboratories to ascertain whether this policy is working effectively, and find that the latter problems seem to be outweighing the former benefits in many cases.*

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1. Introduction

Among the many areas of research in which Joe Peck has made significant, lasting contributions is the economics of research and development (R&D) policies. Two noteworthy examples are Peck and Scherer (1962) on the development and procurement of defense weapons systems and Nelson, Peck and Kalachek (1967) on the government's role in enhancing economic growth by supporting R&D. Each of these books initiated a research agenda and a policy debate that has endured. The first sets forth the fundamental economic and political problems that undermine the efficiency of defense contracting. The second proposes federal support for "generic research centers" -- collaborative R&D institutions involving basic and applied research on the technology base of industries in which fundamental technology is insufficiently appropriable to induce much R&D effort by profit-oriented enterprises.

During the late-1980s and early-1990s, after twenty years of debate among numerous researchers and policy officials and a few policy experiments, the idea of generic technology centers as proposed by Nelson, Peck, and Kalachek, albeit in distorted forms, swept Washington, as government support for subsidized technology-base industrial research centers exploded. Three types of programs emerged. First, the government provided direct subsidies, but with little or no involvement of federal researchers, to R&D joint ventures. The prototypical example is Sematech, a consortium involving the leading manufacturers of semiconductor devices. Second, the government created new commercially-oriented research programs in the national laboratories. The prototype here is the Solar Energy Research Institute (now the National Renewable Energy Laboratory), a national lab devoted entirely to developing the technology base for the commercialization of renewable energy technologies such as photovoltaics, wind, and bioenergy. Third, and the most important financially, the federal government initiated the Cooperative Research and Development Agreement (CRADA), a mechanism that allows national laboratories to engage in joint R&D projects with one or more firms. CRADAs have two objectives: to expand the technical capabilities of the national labs in pursuing their primary mission (e.g., weapons development, basic scientific research, etc.), and to assist industry in finding commercial applications of new knowledge created in the national labs. The prototypes here were activities initiated decades ago by the predecessor of the National Aeronautics and Space Administration, such as cooperative wind tunnels for advancing the design of air frames.

In this paper, we explore a tension between the contributions of the two books by Peck and his collaborators. Specifically, government programs to support technology-base R&D appear to be susceptible to the same economic and political difficulties that have plagued weapons systems development, plus additional problems that arise from the private market test that commercial R&D efforts eventually must pass to be successful. Our focus is on the third, and largest, category of federal initiatives (CRADAs); for a summary treatment of the other two, see Cohen and Noll (1994), and for a more thorough analysis of all three, see our forthcoming book.

2. R&D Procurement Problems

Peck and Scherer (1962) document the well-known problem of cost overruns and performance underruns in defense weapons system development, reporting that the average cost overrun was 220 percent. They also identified the proximate culprit: the cost-plus contract, which blunts the contractor's incentive to deliver the product at least cost. But the most important contribution of this work is the authors' analysis of the difficulties that give rise to a contracting problem between the government and the companies that design and build weapons systems.

The core economic problem arises from the fact that R&D projects are subject to strong uncertainty with respect to costs and technical outcome. Consequently, the seller is incapable of accurately promising either the price of a project or the precise nature of the new knowledge that it will produce. The cost-plus contract is the natural consequence of these uncertainties. As Peck and Scherer observe, "the services attempt to control costs through a detailed audit of expenditures, a set of definitions as to what constitutes allowable costs, and formal approval of product design changes." (Peck and Scherer, 1962: 62.) Of course, intense monitoring creates its own costs, causing indirect cost rates (a major form of transactions costs for government contracts) among contractors to be far higher than for internal R&D projects by commercially-oriented firms.

The uncertainties surrounding weapons system development also serve to prevent the government from using a market mechanism to award initial contracts. When suppliers do not know what performance level they can achieve and how much a project will cost, their proposals in a competitive bidding process convey little information, and in any case result in a cost-plus contract and intensive monitoring, not competition, as the means for controlling price and performance. Consequently, Peck and Scherer conclude: "It is not only that a market system does not now exist in the weapons acquisition process. We can state the proposition more strongly. A market system in its entirety can never exist for the acquisition of weapons." (Peck and Scherer, 1962: 57.)

In addition to the economic implications of technical uncertainty, Peck and Scherer recite a litany of political problems that undermine the efficiency of weapons R&D. Foremost is the instability of project budgets arising from the election cycle and the annual appropriations process. Peck and Scherer observe that this problem is inherent in the American political system, because a change in the preferences of elected officials arising from a national election quite legitimately causes a change in priorities. Private firms, compared to the government, have relatively permanent executive decision makers who share a common objective (profits).

In surveying the literature originating with Peck and Scherer, Rogerson (1994) discusses a great deal of subsequent effort applying agency theory to the problem of contracting for research. The two most important ideas are, first, that the best form of contract for R&D is probably an ex post "prize" based on performance (e.g., a tournament), and second, that the problem frequently is simply too expensive to solve. According to Rogerson, in defense contracting one can interpret the last phase of weapons development -- procurement -- as a prize system, with the winner of the R&D race rewarded with procurement contracts that contain excess profits.

Because in both hot and cold wars, the demand for national security is presumably relatively inelastic, even an expensive system (containing expensive audit requirements, excess profits, and cost overruns due to low-powered incentives in procurement contracts) can usually work for defense. Even in the public sector, however, this system has problematic features, for cost overruns and excess profits, if too large, provide a political weapon to opponents of programs. In the private sector, R&D contracting is very rare (less than 2 percent of private R&D effort is undertaken across corporate boundaries), and, as Monteverde and Teece (1982) discovered in the automobile industry, even production is unlikely to be contracted out if it is supported by significant in-house R&D because firms fear loss of control of their technical knowledge.

Peck and Scherer also discuss the problems of distributive politics that arise from the aspects of defense that make it a form of industrial policy. Although they mention the political problem that arises when government forces a plant to close or a firm to go bankrupt, they report finding few examples in which contractor selection was strongly influenced by such considerations.

The lessons from Peck and Scherer on defense contracting raise some serious questions about the implementation of the policy proposals in Nelson, Peck and Kalachek. Whereas defense weapon development can endure the inefficiencies arising from contracting for R&D because of the plausible hypothesis that the demand for national security is inelastic, commercial programs, which usually have to pass a market test based on superior production efficiency, may be more severely wounded by cost-plus contracts, intensive monitoring, and excess-profit prizes. And, the conclusion that distributive politics is a minor concern in the defense sector (which some dispute), even if accurate, plausibly is too sanguine when applied to commercial projects in which the objective is to improve the status of a specific industry or even firm, not to serve a final-product procurement demand of the government. Our previous work on commercial R&D projects (Cohen and Noll, 1992) found that distributive politics was important in the selection of programs (e.g., synthetic fuels from eastern rather than western coal), in the continuation of failed projects long after they were known to be uneconomic (e.g., Clinch River Breeder Reactor), and in the termination successful projects that threatened to disrupt wealth distribution in an industry (e.g., communications satellites).

Whether technology-base centers will be free of distributive politics is less clear, for they would normally have a small scale and deliver broadly based benefits. But it is also problematic whether government can commit to supporting only technology-base research without embarking on subsidies for prototypes and commercial demonstration. A nasty precedent is that the origin of the Clinch River debacle and the recent Clean Coal Demonstration Program were technology-base programs in breeder reactors and synthetic fuels. It is also problematic whether government can induce private participation in a program that produces only nonappropriable knowledge, rather than help an industry develop appropriable new technical ideas. The problem is the absence of an incentive for firms to support generic technology centers that will not increase their profits because the resulting knowledge is freely available.

In examining the early experience with CRADAs, we seek to explore the practicality of an important category of new, technology-base research programs involving federal research laboratories. The core idea is to find commercial uses of basic research and technology-base knowledge in the national labs, which is in the spirit of the proposal for generic research centers.

3. CRADAs and the National Labs

Approximately 40 percent of direct federal R&D expenditures -- about $30 billion in fiscal 1994 -- is spent for work performed by the government, mostly in approximately 700 national laboratories.[1] The shrinkage of the defense rationale and the rise of the new competitiveness strategy have forced the government to consider two fundamental issues regarding the allocation of its own research expenditures. First, when the point of R&D is to advance commercial technology, the case for undertaking it in a federal research facility is obviously weaker than when the purpose is to develop new technology for the federal government's own activities and purposes. Hence, a reallocation of research away from supporting federal missions, such as national defense, calls into question the wisdom of retaining extensive internal federal R&D.[2] Second, if the first hurdle is cleared so that continuing internal federal R&D is somehow justified, a problem remains about how to reorient R&D so that it is effective for commercial purposes and to facilitate the exploitation of the products of R&D to achieve maximal commercial benefits.

The federal government's primary response to both issues is the Cooperative Research and Development Agreement (or CRADA).[3] A CRADA is a contract between one or more federal research facilities and one or more private entities for carrying out collaborative R&D and for apportioning the costs and intellectual property rights between the public and private participants. Although some cracks have recently developed in the solid bipartisan support for CRADAs, until very recently CRADAs were widely viewed by official Washington as highly desirable. Congress badgered executive agencies for dragging their feet in creating new CRADAs, and under both Presidents Bush and Clinton the Departments of Commerce, Defense, and Energy executed literally hundreds of agreements. Soon after taking office, President Clinton set a goal of dedicating ten to twenty percent of the budget of the national labs for CRADAs (Clinton and Gore, 1993: 9).

These agreements are highly controversial outside of official Washington, and even in Congress enthusiasm has recently dampened. One basis for concern about CRADAs is that they favor federal facilities as the vehicles for carrying out federally-supported commercial R&D. Consequently, CRADAs are regarded by their critics as politically motivated attempts to save white-elephant federal labs, rather than an economically rational approach to improving productivity in the private sector.

A second point of controversy is that CRADAs depart from the historical policy of making both the nature and the results of federally supported R&D publicly available, subject only to secrecy requirements emanating from national security concerns. In the past, the primary means of technology transfer to the private sector was to publicize federally supported research and to make the results freely available to any private party that was interested in them. Most national labs created technology transfer offices, which communicated laboratory research activities to businesses through conferences and publications, and served as a point of contact with anyone who sought to learn more about a lab's research. In contrast, a CRADA not only gives the private partner intellectual property rights in the information produced by joint R&D, but holds confidential the very nature of the project. The question raised is whether the government should help businesses profit from research projects that were subsidized and in part carried out by the government.

Authorizing a CRADA involves a decision to amend the mission of a lab to include assisting private entities in developing commercial applications of the products of the lab's mission-oriented federal work. Typically, this mission redefinition is only partial. A CRADA is expected to be broadly consistent with the federal mission, helping the lab serve its primary mission more cost-effectively through industrial collaboration. Unlike other programs for commercial R&D, the CRADA policy is supposed to provide mission benefits, and, theoretically, is not construed as deflecting the energies of the federal researchers from effective pursuit of the primary purpose of the facility.

At present, there are three basic types of CRADAs. The most common is an agreement between a lab and a private partner (or with a joint venture among private partners) to carry out a well-defined, collaborative research project. These documents are broadly similar because each must satisfy the requirements of the laws that authorized CRADAs, and in many cases are based on a standard form that the agency uses for all or most CRADAs. But the key feature of this type of CRADA is that the project is narrowly defined, and its nature and scope are matters of bilateral negotiation between the lab and a partner.

The second type of CRADA is a more general agreement specifying a broad program of research, and negotiated between a lab -- or, in a few cases, several labs -- and an industrial consortium. The agreements frequently are implemented through a series of specific CRADAs with the consortium, within the overall general agreement that commits the parties to a general program of collaboration. The intellectual property rights are then shared among the consortium members.

The third type of agreement is a "master CRADA" covering an area of research that is the blueprint for several different CRADAs, each for a particular project with a particular firm that fits into the overall scheme of the master CRADA. This form is typically negotiated with an industrial trade association or consortium, but the nongovernmental partners do not necessarily collaborate on projects or share intellectual property rights across the individual agreements. The main purposes of these agreements are to announce priorities and to publicize a strategy for contributing to R&D on a particular technology.

4. The Economics and Politics of CRADAs

The enthusiasm for involving the national labs in commercial R&D, as apparent from the elimination of most of the restrictions on partnerships with industry during the 1980s and the vocal encouragement of them by political leaders, has complex roots in both politics and economics. Initially both the economics and politics worked to favor this institutional innovation; however, only recently have the problematic aspects of the economics begun to cause political problems.

The political case for CRADAs is clear. Turning a significant part of the effort of national labs to supporting commercial R&D projects in collaboration with industry provides obvious short-term political benefits. Companies that are CRADA partners are pleased to be subsidized, and pleased still more to have exclusive rights to the technologies developed at the labs by government researchers. Likewise, national labs -- especially the weapons labs in DOD and DOE -- see CRADAs as a means to avoid at least some of the budget cuts arising from the end of the Cold War and the concomitant reduction in political support for all defense-related activities.

CRADAs have still another advantage in that they are less susceptible to an important political liability of many other commercial R&D programs. CRADAs normally are not awarded on the basis of a competition, but are available to any company that can interest the lab and its supervising agency. Hence, a large number of companies that are interested in collaborating with a lab need not necessarily be disappointed as long as their areas of technical expertise mesh. Because competitors in the same market are likely to use roughly the same technology, usually either all or no competitors are plausible candidates for a CRADA. As a result, the program can avoid picking winners and losers, and hence being perceived as unfair, as long as the government's resources for creating CRADAs matches the demand.

The liabilities of CRADAs arise from their economics.

Because most effort at national labs is either very basic or applied to defense weapons, the relevance of most of the work at national labs to commercial technology appears distant at best. The commercial appeal of R&D on nuclear weapons, ballistic missiles, and aircraft that fly several times the speed of sound or achieve orbit is certainly not obvious. Moreover, the applications orientation of many national labs is not closely compatible to successful commercial R&D. Federal labs tend to place less emphasis on cost, and more emphasis on performance, in comparison to commercial R&D. And, the basic research labs -- notably, the facilities engaged in research in particle physics -- seem even more removed from any immediate practical application. Furthermore, like defense contractors, the national labs are weighed down by the extensive monitoring of all government research contracts that drives up administrative costs and delays projects. Hence, the question that arises is how the national labs could be sufficiently attractive partners to industry that they could become a significant factor in commercial R&D.

Even if the labs can play a significant role in commercial R&D partnerships, a large CRADA effort could undermine their ability to serve their primary mission as they bend the objectives of their projects towards the different priorities of industry. The Congressional Office of Technology Assessment, otherwise an enthusiast for government support for commercial R&D, has expressed doubts about the potential scope of CRADAs.

> "For the longer-term future, R&D partnerships with industry, _per se_, are not likely to provide a satisfactory central mission for the weapons labs. As public institutions, the labs' existence is best justified if they serve missions that are primarily public in nature." (U.S. Office of Technology Assessment, 1993: 2.)

Two outside advisory panels that studied the potential of DOE labs for commercial R&D reached essentially the same conclusions (Secretary of Energy Advisory Board, 1992 and 1995).

The economic case for CRADAs is not conceptually frivolous. The essence of the argument is that national labs and industrial R&D organizations have R&D complementarities. They attack similar problems, but because of differences in priorities they attack these problems in different ways, or push discoveries in somewhat different directions. Indeed, if there were not differences in capabilities and priorities, there would be less scope for mutually beneficial collaboration.

This rationale for public-private R&D collaboration parallels the rationale for potentially productive collaboration between private entities. As argued by Nelson and Winter (1982), R&D is not correctly conceptualized as analogous to ordinary production. In R&D, the outputs of a project are usually quite unpredictable, and in some cases the output -- the new insight about how to make a new or improved product -- is completely unexpected. As a result, the particular applications that are developed from an R&D project can depend, idiosyncratically, on the mission of the organization in which the R&D is undertaken. Because the orientations of national labs and private industrial R&D organizations are so very different, one side may simply ignore the value of a research output to the other.

The scope and magnitude of collaborative R&D between national labs and industry are surely not matters to be ascertained by theoretical argument; instead, they can best be assessed empirically, by observing what actually has happened in the first few years of the CRADA program. Unfortunately, the government has been especially closed in providing solid information about CRADAs -- a policy that was deliberately set in motion by provisions of the enabling statutes that protect the confidentiality of the agreements. CRADA proposals and reports are exempted from the Freedom of Information Act, and the agreements bind the parties not to reveal any proprietary information brought to the CRADA or any research results emanating from it without their mutual consent. Whereas some agencies make the titles and partner identities available, and in some cases the cost, agencies are not obliged to do so, and will not if their partner objects. Moreover, none of the agencies responsible for managing the CRADA program regularly collects information about the extent of its CRADA activity, much less performance data about the joint projects. Hence, nearly all of the available information takes the form of raw "CRADA counts" that do not differentiate between small, narrowly defined projects and massive, broad agreements with large industrial consortia. Moreover, the only source for this information is the publications of Grant Stockdale (1993, 1994a, 1994b, 1994c).[4]

Table 1 summarizes the CRADA counts and Table 2 the minimal available information on the financial significance of CRADA activity. The first table classifies all CRADAs on the basis of their titles, a process that is crude because CRADAs often have multiple purposes and because, in any case, the titles frequently reveal very little information. The classification scheme is intended to reflect the principle industrial targets of the projects, with definitions in the notes to Table 1.

[Tables 1 and 2 about here]

The number of CRADAs executed is estimated to be 514 in 1992 and 880 in 1993. These figures are underestimates of the number of agreements executed. One of the most active CRADA agencies, NASA, is excluded because until very recently it has refused to collect such data. The data also overstate the number of distinct projects, for in some cases CRADAs with industrial consortia are executed separately with each member of the consortia, even though they all cover the same collaborative research effort. Table 3 contains a list of some consortia and the number of CRADAs executed for them.

[Table 3 about here]

As shown in Table 1, the Departments of Defense and Energy are the leaders of the CRADA program; most likely, NASA would be in this category as well, which Stockdale estimates to have executed about 300 Space Act Agreements (their CRADAs) in 1993. Agriculture (primarily the Agricultural Research Service) and Commerce (primarily through NIST) are also important. The other agencies are minor, including the Department of Health and Human Services (HHS), the home of the National Institutes of Health (NIH) -- the nation's most important source of biomedical R&D. Given the enormous growth of the biomedical technology, the minimal current success of HHS and NIH is of considerable interest, and is examined more thoroughly in the next section.

The substantive composition of CRADAs indicates that they are aimed mostly at high-technology industries, especially computers and semiconductors (classified as information technology in Table 1) and biotechnology (classified as biomedicine and other biological), but also aerospace, chemicals, and energy. In most cases, these are in areas related to traditional agency missions. Relatively few CRADAs are oriented toward the most important traditional heavy industries, such as autos and primary metals, or any form of manufacturing outside of the high technology sectors. And, most of the few traditional manufacturing CRADAs, especially in NIST, are for the development of electronic equipment that is used in research or as control devices in manufacturing.

The demand for CRADAs greatly exceeds the supply. Program offices in DOE report that two to four times as many companies seek CRADAs as can be accommodated (Wells, 1993: 7). The primary problem is that the government share of funds is almost always derived from "reprogramming" -- that is, reorienting the existing R&D budget to CRADA activities. Agency missions plus congressional earmarking place significant limits on the amount that can effectively be reallocated to CRADA activity. This fact is important, because it means that the program can create winners and losers in the same industry.

Estimates of the costs of CRADAs have only been unearthed by Stockdale since 1993, and even here the record is very incomplete. The most complete data are available for DOE, which is estimated to have spent about $1 million each on the 336 CRADAs for which it provided cost estimates. Data are available on the partner's costs for 289 CRADAs, and these averaged about $1.3 million. Based on the data contained in Table 2, the total federal share of CRADA costs was about $1 billion, with at least another $1 billion from industry.

These data include minimal expenditures for the highly visible consortia that have been created since 1992. The Clean Car Initiative is targeted to spend $500 million per year for ten years, beginning in 1997, and AMTEX (the consortium involving 500 companies in the textile and clothing industries) is slated to spend $100 million annually for ten years, beginning in 1995, as reported in Stockdale (1994b). Both targets are to be reached through CRADAs, extracted from reprogrammed money for mission R&D. Federal officials who manage the CRADA effort talk optimistically of developing several more master CRADA consortia with annual price tags in the $100-500 million range (Stockdale, 1994b). Where the agencies will find this much money has yet to be revealed.

The data in Table 2 significantly understate the government's cost, for they do not include the administrative effort devoted to the program. All CRADAs require negotiation between the lab and private partners before the CRADA is executed, and review and approval at laboratory headquarters.[5]

What conclusions can be reached about the CRADA program from these fragmentary data? Obviously, CRADA activity is growing rapidly, but it is a long way from the bottom end of the Clinton-Gore target of 10-20 percent of national lab activity. CRADAs account for about 3 percent of expenditures at the labs. Most likely the program could be much larger, but conflicts between agency missions and technology transfer are a serious problem, especially in an era of declining real federal R&D expenditures. Agencies have focused effort on high-technology activities; however, the political commitment to textiles, the Clean Car Initiative, and others like these indicate that heavy manufacturing industries may become more important. Thus, two major concerns are likely to engender controversy in the immediate future: the conflict with lab missions, as more money is reprogrammed to satisfy demands from industry for more CRADAs, and the conflict between high-technology commercial projects, which fit best with the capabilities of the national labs, and projects for industries with more mature technologies and little compatibility with the national labs.

5. CRADA Property Rights and Scandals

The basic economics of the CRADA program does produce two unequivocal reasons why the long-run political attractiveness of the program is limited. One is the issue of intellectual property rights in research results, and the other is special relationships that develop between a lab and its suppliers. Both can cause the CRADA program to be seen as unfairly advantaging some firms at the expense of others, despite the fact that, in principle, CRADAs are available to everybody.

The complementarity rationale for CRADAs explains why private industry might be interested in work at national labs, but this is insufficient to motivate collaborations. In order for a business to want to enter into a CRADA, it must expect to profit from its contribution to the joint R&D effort. And, the prospects for profitable exploitation of CRADA work depend on retaining property rights in the results of the research.

The government only slowly and reluctantly expanded the scope of activities in which private partners could retain proprietary rights in collaborative work with the labs, a pace that reflects a fundamental economic and political dilemma in the program. A policy that attracts private interest in CRADAs is certain to produce some commercial projects that are highly profitable. The economically important issues behind anecdotes about successes from CRADAs are, first, whether open or closed federally-supported commercial R&D is more cost-effective in advancing productivity and consumer welfare, and second, whether the combination of some big winners with many other modest successes and financial failures yields an especially high rate of return on investment to private CRADA partners. Because politics is almost always debated in terms of captivating anecdotes and sound bites, not comprehensive analysis of the underlying issues, a handful of cases in which private partners derive enormous profits are likely to be damaging to the program.

At the heart of the problem is the nature and assignment of rights to the products of CRADA R&D. Because the legal issues surrounding intellectual property rights in CRADAs are well-defined and broadly similar, the agreements themselves are generally very much alike in their treatment of these issues. DOE's master CRADA for the Computer Systems Policy Project is typical, and among the important provisions are the following.[6]

* Article VIII confers on each party the obligation to designate any information produced in connection with the CRADA (even if by a single person employed by only one partner) as "protected CRADA information" which can not be divulged to any other party for five years except by mutual agreement.

* Article XII deals with rights of pre-publication review of research papers and oral presentations by personnel involved with the CRADA. According to the language of the master CRADA, "the Parties recognize that a principal objective of this CRADA is to provide business advantages to Participant." (Stockdale, 1993: 83.) (The "Participant" is the nonfederal partner.) Publications from CRADA research projects are treated essentially

the same as work in industrial labs or top-secret military research projects.

* Articles XIII and XV deal with the rights to copyrighted materials, masks, and inventions. The basic theme is that the government has a nonexclusive right to use all intellectual property, but only for DOE use (copyrights) or federal government use (inventions). The government retains title to intellectual property developed by its employees, and shares title to material developed jointly, but the partner has an option on an exclusive license for commercial use of all intellectual property.

* Article XX, in implementing the competitiveness purpose of the program, specifies that all CRADA R&D must be performed in U.S. facilities, and that for two years after the completion of the CRADA follow-on work to commercialize the research products must be substantially undertaken in a U.S. facility. In addition, the accompanying Letter of Agreement further states that the private partners agree not to transfer any manufacturing know-how developed through the CRADA to a foreign manufacturer other than their own subsidiaries for a period of two years, but even here there is an escape clause dealing with the possibility for an exception for products that can confer competitive advantage on an American firm that buys or uses the product.

The basic CRADA for the National Institute of Standards and Technology is broadly similar to the others. NIST's CRADA partner can exercise an option to an exclusive license to all inventions emanating from the CRADA, regardless of whether the patent holder is the partner, NIST, or both together. In turn, all manufacturing activity arising from CRADA research products must take place in the U.S. The main exception is that data produced collaboratively in carrying out the CRADA cannot be copyrighted by either party in the U.S. and only by NIST in foreign countries. A partner in a NIST CRADA can copyright only data produced solely by its employees.

These master agreements make clear the basic CRADA deal. The point is to help U.S. firms compete more effectively internationally -- while simultaneously generating more U.S. manufacturing jobs. To accomplish this objective, the government seeks to erect barriers against diffusion of technology to other nations. The instruments for achieving this objective are to give U.S. firms all the intellectual property rights, and to require that they not pass them on to foreigners except, to a limited degree, their own foreign subsidiaries. Thus, privatizing the technical information emanating from CRADAs is a necessary part of the program, given its parochial objective. This approach represents the fundamental distortion of the program from the original proposal by Nelson, Peck and Kalachek for generic technology centers, for it commits CRADAs to focus on appropriable technologies that can be kept away from foreigners, rather than technology-base information that private industry has inadequate incentive to produce.

The property rights conferred on private partners can be especially valuable, and some examples have already emerged --

and generated considerable political controversy. The focus of most of the attention has been drugs emanating from CRADAs involving the National Institutes of Health.

The first firestorm arose over AZT, a drug for treating patients infected by HIV. AZT emanated from a CRADA involving the Burroughs Wellcome Company, which the company subsequently marketed at a price of $2,000 to $10,000 for a year's supply.[7] In 1989, NIH officials suffered through embarrassing oversight hearings in which members of Congress expressed considerable dismay that a government lab had been party to the creation of such a profitable bonanza for a private company -- largely at the expense of government, which directly or indirectly through tax subsidies pays most of the nation's health care bills.

In response to the AZT controversy, NIH adopted a "reasonable pricing" clause for future CRADAs; however, even though NIH was the only agency to adopt such a condition, the agency continued to receive congressional criticism because of its willingness to let the private partner determine what constituted a "fair" price and because the agency had not adopted any specific standards or rules for deciding whether a company was in compliance with the requirement.[8] Then-Director of NIH Bernadine Healy responded by appointing a commission to examine how NIH could more effectively implement its pricing guidelines, but in 1993 she eventually concluded that NIH was not able, by virtue of its expertise and experience, to undertake anything remotely resembling economic regulation of pharmaceutical prices.

As a result, she concluded, the NIH pricing requirement has no teeth.[9]

Soon after the AZT controversy, another firestorm arose over the pricing of Taxol, a cancer drug developed from a CRADA at the National Cancer Institute. Taxol allegedly was priced at 200 times its manufacturing cost, which induced Senator David Pryor to state during a committee hearing that NIH CRADAs "have given the drug manufacturers a legally sanctioned license to price gouge the American public." (Rhein, 1993: 5; see also U.S. House of Representatives, 1993.)

In practice, NIH has engaged in negotiations with CRADA partners over drug prices, and claims some success in forcing price reductions. But this very success has created still another controversy: whether the implementation of the price clause will cause firms not to want to execute NIH CRADAs. In August, 1994, an advisory panel to NIH, which contained industry officials, NIH personnel, representatives from citizens groups, and even congressional staff, concluded that NIH should drop its "reasonable pricing" clause (Rhein, 1994).[10] The panel's recommendation followed from several points: the fact that other agencies executed CRADAs with drug companies that contained no such clauses, the absence of any statutory basis for the involvement of NIH in drug price regulation, and the threat from several companies that they would no longer engage in CRADAs with NIH. Meanwhile, some members of congress are attempting to draft legislation that would require an agreement about pricing between the Department of Health and Human Services and a private partner before the latter could market any drug emanating from a CRADA. And, to add fuel to the fire, a New York patent attorney who serves on the panel claimed that the U.S. Department of Justice had recently decided not to enforce drug patents issued to firms participating in CRADAs. Most likely, the legal basis for this decision would be the fact that CRADAs preserve for government the right to use CRADA inventions for government purposes, and the government pays for more than half of the expenditures on prescription drugs.

The controversy regarding NIH CRADAs has made NIH a relatively minor player in executing biomedical CRADAs. Table 1 shows that HHS now creates only about twenty CRADAs per year; however, Table 4 shows that in the early history of the program, HHS was as important as Defense and Energy in creating these collaborations. In brief, HHS created many early CRADAs because it had many commercializable research results, and is now dying as a source of CRADAs because the early agreements were a success!

The Taxol dispute revealed still another political vulnerability of CRADAs. Taxol, a derivative of yew bark, was developed under an NCI research grant, but its potential as a cancer treatment was not recognized for nearly two decades. In 1989-90, NIH decided to enter into a CRADA to develop the drug commercially. Four firms sought to enter the agreement. Two posed no political threat for they were foreign: one French, the other Japanese. The remaining two were American, one the pharmaceutical giant Bristol-Myers Squibb and the other Unimed, a small company with no prior experience in cancer drugs. NIH chose Bristol-Myers, bringing charges of unfairness and an investigation by the Regulation, Business Opportunity, and Energy Subcommittee of the House Small Business Committee (U.S. House of Representatives, 1993). The Small Business Committee has jurisdiction because the act that is the wellspring of the CRADA program -- the Bayh-Dole Act of 1980 -- requires a preference for small businesses in commercializing intellectual property developed from federal funds. Hence, the concern here was in part that NIH unfairly created a loser, and in part picked a big multinational giant over a small business.

The dispute over the Taxol award is not unique. In 1992, Chem Service, Inc., sued the Environmental Protection Agency because EPA's Environmental Monitoring Systems Laboratory had executed CRADAs with several of Chem Service's competitors but refused several CRADAs with Chem Service. The complaint held that the EMS Lab CRADA policy conferred unfair business advantages of the firm's competitors. In early 1993, the suit was dismissed on the grounds that the Federal Technology Transfer Act of 1986 conferred no obligation on EPA to protect the interests of specific firms, but rather to promote the general competitiveness of American industry.[11]

Although EPA won the battle, the case provides another illustration of the fact that CRADAs are not free of the political problems associated with picking winners -- and therefore creating losers. A more pertinent example is a $70 million CRADA entered into in 1993 between Cray Research and two national labs for supercomputer development. After intense objections from other supercomputer manufacturers, and pressure from congress, the CRADA was dropped.

These recent disputes reveal that CRADAs suffer from a problem similar to other government-sponsored commercial R&D projects that are done outside the context of either open research or an industry-wide consortium. When CRADAs succeed, they generate opposition if (1) the private partners make too much money or (2) the losers complain that the government is unfairly determining the outcomes in competitive markets. Hence, the CRADA program can be expected to produce some politically driven but economically undesirable biases in project selection: an emphasis on CRADAs that are more removed from near-term commercialization, a search for projects that can be implemented through industry-wide consortia (and hence that are cartelizing but avoid creating losers), and a skittishness on the part of mission agencies to allocate commercializable work to their captive labs. The long-term and consrtium biases would work to make CRADAs more like the original proposal for generic technology centers, but the drive for secrecy and appropriability due to the orientation towards international competitiveness and the skepticism arising from conflicts with public missions would move away from the original proposal.

6. Conclusions

The CRADA program is a success in that industry is pounding on the doors of the national labs -- especially the defense labs and NIST -- to engage in cooperative projects. And, thus far, judging from the distribution of projects by technology and industry, the program does not appear to have significantly deflected agencies from their primary missions.

Behind this generally rosy picture, however, lurk some very significant problems. Some CRADA-based consortia enjoy widespread, bipartisan political support, are likely to cost hundreds of millions if not billions of dollars, have dubious economic rationales, and represent significant deflection of labs from their missions. These consortia have not yet obtained the level of federal backing that is contemplated for them, but if and when they do, the argument about whether these CRADAs are cost-effective means of advancing commercial technology or simply a last gasp to avoid the politically unpleasant task of closing white elephant labs is likely to become far sharper.

In addition, the cracks in CRADA popularity due to the private profitability of some partnerships are likely to become much more significant. Biotechnology CRADAs are by no means confined to NIH, the agency that thus far has taken all the heat; NIH accounts for only about one-third of biomedical CRADAs, and one-sixth of all biotechnology projects. And, the government is just as susceptible to this problem in other areas, such as information technology and energy. Most likely, it is only a matter of time before angry members of Congress find scandals of the type surrounding AZT and Taxol in other agencies.

Another problem facing CRADAs arises from their industrial organization. The CRADA program is beginning to make the same kinds of enemies that other direct support programs made in the past. Type I enemies are disappointed competitors that have been excluded from a highly profitable CRADA. Type II enemies are firms that are suppliers or customers of an industry-wide consortium that becomes a cartel. Thus far, CRADAs have only made Type I enemies -- like Chem Service, Unimed, and supercomputer manufacturers -- and no Type II opponents. But if CRADAs are really worth the billions of dollars annually that is now being spent on them, and the even greater billions planed for the next few years, the program can not avoid creating more enemies.

Thus far, the private partners in CRADAs have managed to avoid the extensive monitoring and audit requirements that are imposed on the labs. But this benign circumstance is unlikely to persist. The pressure on NIH to regulate the prices of drugs derived from NIH patents reflects the same fundamental problems that force extensive monitoring and audit requirements in government R&D contracts, and limit the extent to which the Department of Defense can use excess profits in defense procurement to reward winners in an R&D race.

The core of these problems lies in the incentive problem facing the government in designing CRADAs. In attempting to make the national labs effective generic technology centers, the government needs to have extensive participation by industry in order to focus the research and to transfer knowledge effectively. Industry, in turn, will not commit significant research resources to collaboration with the labs unless industry obtains important property rights in the results of the collaboration and is allowed to commercialize these rights. Government, in turn, can not withstand the criticisms that such a system engenders: that private industry is profiting from ideas created with taxpayer dollars, and that the government does this in a way that either forms a cartel or creates industrial losers (the firms left out of a successful CRADA). Both potential solutions to this problem are imperfect. First, government can pay for all the work and give the research product away to everyone. Because of the necessity to involve the private sector, this means imposing government monitoring requirements on private partners and engaging in cost-plus contracts (since the private partners have no other incentive to create nonappropriable technological knowledge). Second, the government can form R&D cartels, in which the private sector pays for its share of the work, and then regulate the profitability of products emanating from the collaboration, as the government has tried to do, thus far futilely, at NIH. Neither approach holds out much hope of being especially efficient.

The problem with generic technology centers as proposed by Nelson, Peck and Kalachek is most assuredly not that the economic logic for them is weak. Instead, the problem is that they bring to the private economy some problems associated with the defense sector, as so elegantly described by Peck and Scherer. We do not know how to contract for R&D in a manner that leads to efficiency in production and that keeps the scope of a program narrowly focused on producing public goods, free from the distortions of distributive politics. The CRADAs are no exception. While they will undoubtedly produce some useful new commercial technology, and will prevent some of the downsizing of the national labs that will inevitably follow the downsizing of the defense sector, their long-run role will be limited by these factors.

Notes

* University of California, Irvine, and Stanford University, respectively. The authors are grateful to research support from the American Enterprise Institute and the Markle Foundation, neither of which bear any responsibility for the content of this article. The authors also thank Scott Wallsten for research assistance.

1. The exact number of national labs is arbitrary, and depends on how one counts agencies with several separate research facilities that are jointly managed. As good a number as any is 726, the official White House number in Clinton and Gore (1993), p. 8.

2. The laboratories are very much aware that the end of the Cold War may bring on a wave of lab downsizing and closings, like the base closings begun in the mid-1980s. For a description of how Los Alamos National Laboratory is attempting to reorganize in order not to be the loser in the prospective reduction in the size and number of nuclear weapons labs, see McCartney (1993).

3. The other main response is to allow inventors and laboratories to keep most of the income from the licensing of inventions by their employees. The Bayh-Dole act of 1980 did this for nonfederal R&D contractors, and the Federal Technology Transfer Act of 1986 extended the policy to federal employees at government-owned and operated labs. For a description of the latter program, see U.S. General Accounting Office (1992).

4. Technology Publishing Group provides this information primarily for the benefit of companies that are interested in forming a CRADA, and it extracts an extravagant price for its data. With due respects to Mr. Stockdale and his praiseworthy effort in unearthing the data that are available, the fact that data at least equal in quality to that published by Technology Publishing Group is not regularly collected and published by the government, and that Stockdale has so much trouble extracting information from the agencies, is nothing less than scandalous.

5. For more details on how the CRADA process works, see Wells (1993). An interesting comparison of the evolution of the master CRADAs for the Clean Car Initiative, an auto consortium, and AMTEX, the textile industry consortium, see Stockdale (1994b).

6. The complete "Letter of Agreement" and "CSPP Master CRADA" (including the articles summarized here) are contained in Stockdale (1993), p. 75-91.

7. Estimates of the price of AZT are subject to amazingly wide variation. The range cited in the text is taken from Anderson (1994) -- $2,000; NIH Director Bernadine Healy as quoted in Health Care Daily, February 25, 1993 -- $8,000; and National Cancer Institute Director Samuel Broder, as quoted in Biotechnology Newswatch, December 2, 1991 -- $10,000. Most likely, the numbers refer to the time trend of prices after initial introduction.

8. Biotechnology Newswatch, December 2, 1991.

9. Health Care Daily, February 25, 1993.

10. One panel member, William Terry of the Brigham Medical Center in Boston, when asked why NIH adopted the reasonable pricing clause, responded: "It's a puzzle to many of us." Obviously, he was not a part of the AZT scandal three years earlier, or he would have known that NIH adopted the clause because congress pressured it to do so.

11. Chem Service, Inc. v. Environmental Monitoring Systems Laboratory, et al. (1993).

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Table 1

Number and Industry of CRADAs by Agency, 1992-93

Agency	1992 Total	1993 Total	Distribution of 1993 CRADAs by Industrial Technology* Biological Med.	Biological Other	Manufacturing Aero	Manufacturing Auto	Manufacturing Chem	Manufacturing Other	Inf. Tech.	Comp. Soft.	Energy	Other
Agric.	41	103	1	47	1	0	12	31	0	1	2	8
Comm.	86	144	1	2	17	1	21	33	44	7	8	10
Defense												
Air F	24	73	1	2	7	1	2	2	33	16	3	6
Army[a]	92	87	19	6	2	4	3	27	9	3	0	14
Navy	27	46	9	0	4	2	1	10	13	5	0	2
Total	143	206	29	8	13	7	6	39	55	24	3	22
Energy	160	368	14	10	21	20	35	86	86	18	61	17
EPA	20	5	1	2	0	0	0	0	0	0	1	1
HHS	53[b]	25	25	0	0	0	0	0	0	0	0	0
Inter.	3	15	0	1	0	0	3	8	0	0	0	3
Trans.	8	14	0	0	12	0	1	0	0	0	1	0
TOTAL	514	880	71	70	64	28	78	189[c]	185	50	76	61[d]

* To the extent possible, classifications are based upon the identity of the target industry; however, in many cases either the target sector was not possible to ascertain other than manufacturing in general, or more than one sector was involved. For example, a project dealing with ceramics could apply to high-performance aircraft, autos, energy, or general manufacturing. The follwing general classification principles were followed: biological projects were classified as biomedical or biotechnology regardless of application; computer projects were classified by industrial application unless they dealt specifically with operating systems, general applications software, systems integration, or mathematical algorithmm; energy includes fuels, manufacturing of electric generation equipment, and energy-efficiency projects for consumer goods but not for autos and aerospace; and projects for environmental protection were classified by industry except toxic cleanup and emissions monitoring.

a. Includes the Construction Productivity Advancement Research Program, which others sometimes leave out. The number of CPARP projects was 12 in 1992 and 5 in 1993.

b. The 1992 numbers include the cumulative historical total for the Centers for Disease Control and the Food and Drug Administration, and so cannot be compared to 1993. For the NIH, the numbers were 24 in both years.

c. Includes 6 for food and 19 for primary metal products.

d. Includes 3 agricultural practice, 2 basic, 15 construction, 6 education, 13 environmental, 1 forest management, 3 management/finance, 3 mining, and 15 unknown or unclassifiable.

Source: Stockdale (1993, 1994a).

Table 2

Costs of CRADAs, 1993

Agency	Number of CRADAs with Data	Government Funds ($ millions) Total	Average	Private Funds ($ millions) Total	Average
Agriculture	63	10.3	0.16	na	na
Commerce	144	27.2	0.19	27.2*	0.19
Energy	336**	324.8	1.02	363.8	1.26
EPA	5	.8	.16	na	na
TOTAL	548	363.1	0.66	491.0	1.13

* Department of Commerce number is based solely on the agency's requirement that the CRADA partner bear at least half the cost, so this figure is a lower bound.

** Private contribution data available for 289 Department of Energy CRADAs.

Source: Stockdale (1994a).

Table 3

Selected CRADA Consortia

Consortium (number)	Members with Separate CRADAs, 1992-1993
Advanced Biosensors (7)	Abbott Labs, Beckton Dickinson, Ciba-Corning, Dow, du Pont, Miles, Ohmicron
ISDN Users' Forum (15)	AHK & Associates, Ascom Timeplex, Chase Research, Department of the Navy, Fujitsu, Georgia Tech, Hayes Microcomputer Products, Intecom, National Information Technology Center, Network Communications, North Carolina State University, Northern Telecom, Siemans-Stromberg-Carlson, Telebyte, University of West Virginia
Modeling of Casting Metal Alloys (17)	Allied Signal, American Foundaryman's Society, Auburn University, Case Western Reserve, Departmnt of the Interior, EG&G Idaho, General Electric Aircraft Engines, General Motors (Allison Gas Turbines), Howmet, MIT, PCC Airfoils, Purdue, UES, Inc., University of Alabama, University of Arizona, University of Illinois, Worcester Polytechnic Institute
Polymer Blends (6)	Aristech, Armstrong, Goodyear, Raychem, Rohm and Haas, 3M
Intelligent Processing of Ceramic Powder (6)	Cercom, Coors Ceramic, Eaton, Kerr-McGee, Matec Applied Systems, Norton Industrial Ceramics
BACnet Interoperability Testing (5)	Delta Controls, Johnson Controls, PolarSoft, Snyder General, Trane
Ceramics Machining	Ceradyne, Cincinnati Milicron, Eaton, Eonic, Ford, General Electric, General Motors, Norton, Penn State, SAC International, Sonoscan, Stevens Institute of Technology, Texas A&M, Therm Advanced Ceramics, Tower Oil, University of Maryland, W.R. Grace

Source: Stockdale (1993, 1994a)

Table 4

Number of CRADAs in the Department of Health and Human Services

Fiscal Year	Number of New CRADAs
1987	98
1988	145
1989	225
1990	239
1991	261
1992	63
1993	25
1994	19 (est.)

Source: Personal communication, Grant Stockdale, Publisher, CRADA Handbook