Public/private partnerships in the United States

By: Albert N. Link

Albert Link (1999) Public/Private Partnerships In The United States, *Industry and Innovation*, 6:2, 191-217, DOI: 10.1080/13662719900000011

Abstract:

As greater attention is given to public support of private-sector R&D, it becomes imperative for policy makers to be able to offer an economic rationale for publicly-supported partnerships as well as a means for evaluating such relationships. This paper describes the experiences of the United States in forming public/private partnerships and how they have been evaluated.

Keywords: public/private partnerships | research and development | technology transfer

Article:[1]

As greater attention is given to public support of private-sector research and development (RW) by participants in the innovation process, it becomes imperative for policy makers to offer an economic rationale for their support of public/private partnerships as well as to formulate and demonstrate means for evaluating such relationships. The purpose of this paper is to describe the experiences of public/private partnerships as a tool to support industrial R&D in the United States. These experiences may therefore serve as a guide to other industrial nations as they too reflect on the efficiency and effectiveness with which public funds are allocated in support of innovative activities.

The first part of this paper provides an overview of the economic rationale for public/private partnerships in terms of the relationship between risk and the closely related difficulties of appropriating returns to investments in technology (e.g. R&D), and the effect of direct financing through partnerships on the expected returns to R&D. Following this, a taxonomy of US public/private partnerships is posited in terms of the intended economic objectives of the

---

[1] This paper is based on a study funded by the OECD Committee for Scientific and Technology Policy (Link 1998b). OECD drew upon aspects of the broader study in their report, "Technology, Productivity and Job Creation: Best Practices in Technology and Innovation Policy" (1998). Extremely useful and appreciated comments and suggestions on earlier versions of this paper came from Jean Guinet of the OECD. Robert Cam of SRI International. John Jankowski of the National Science Foundation. John Scott of Dartmouth College, Gregory Tassey of the National Institute of Standards and Technology, and Chuck Wessner of the National Academy of Sciences.

partnership. Preliminary data are described, and a lower-bound estimate of public expenditures toward public/private partnerships in the United States is then offered. The paper continues with an overview of the institutional history of US public/private partnerships. Nong with a description of each program, specific evaluation efforts that have occurred are noted and discussed. The Department of Commerce's Office of Technology Policy's general evaluation of public/private partnerships is then presented in terms of their perceived successes. The paper concludes with summary comments.

For the purposes of clarity and ease of presentation, the term "public" refers herein to any aspect of the innovation process that involves governmental resources, be they federal or state in origin. While universities, both public and private, rely on public funds in support of their basic research, they are not considered herein so as to bound and focus the discussions that follow. The term "private" is similarly defined to refer to industrial resources. And, the term "resources" is broadly defined to include financial resources, research resources, and infrastructural resources, meaning resources that affect the general environment in which research takes place. Lastly, the term "partnership" refers to any innovation-based relationship, including, but not limited to, direct collaboration in R&D.

Surprisingly, there is not a uniformly accepted definition of "partnership" in the academic or policy literature. For example, Coburn (1995: 1) uses the term synonymously with co-operation. Therein, he defines co-operative technology programs as "public-private initiatives involving government and industry—and often universities—that sponsor the development and the use of technology and improve practices to measurably benefit specific companies". And, in a very narrow sense, Link and Bauer (1989) define research joint venture partnerships as an arrangement through which firms jointly acquire technical knowledge. The working definition of partnerships used in this paper follows in spirit from that used by the Council on Competitiveness (1996: 3):

> Partnerships are defined ... as cooperative arrangements engaging companies, universities, and government agencies and laboratories in various combinations to pool resources in pursuit of a shared R&D objective.

ECONOMIC RATIONALE FOR PUBLIC/PRIVATE PARTNERSHIPS

Government's role in innovation

Many date the origin of a US domestic science and technology policy with Vannevar Bush's *Science–the Endless Frontier* in 1945. Certainly, Bush's views about science and the role of universities in sustaining the nation's science base had a profound impact on the scientific community of his time as evidenced by the soon thereafter founding of the National Science Foundation in 1950.

Bush's legacy is one of policy focus, emphasizing clearly the importance of basic research in the innovation process. However important, Bush was not articulate about the economic rationale for government's role in innovation, much less about addressing issues of public/private partnerships. Bush did articulate an intellectual rationale for public support of basic research and research related to issues of national security, industrial growth, and human and health welfare (National Academy of Sciences 1995).

The first formal domestic statement, *US. Technology Policy,* was released by the Office of the President in 1990, coincidentally during the Bush Administration. As with any initial policy effort, this was an important general document. However, precedent aside, it failed to articulate a rationale or role for government's intervention into the private sector's innovation processes. Rather, much like *Science–the Endless Frontier,* it implicitly assumed that government had such a role, and it then set forth a rather general goal (1990: 2):

> The goal of U.S. technology policy is to make the best use of technology in achieving the national goals of improved quality of life for all Americans, continued economic growth, and national security.

President Clinton took a major step forward in his 1994 *Economic Report of the President* by articulating first principles about why the government had this role in innovation and in the overall technological process (p. 191):

> Technological progress fuels economic growth ... The Administration's technology initiatives aim to promote the domestic development and diffusion of growth- and productivity-enhancing technologies. They seek to correct market failures that would otherwise generate too little investment in R&D ... The goal of technology policy is not to substitute the government's judgment for that of private industry in deciding which potential "winners" to back. Rather the point is to correct [for] market failure ...

This role for government traces back at least to the writings of Bator (1958). TI1e conceptual importance of identifying market failure for policy is also emphasized in OMB (1996) and summarized in OECD (1998). But, the *Economic Report* did not expand on how to correct for market failure much less discuss appropriate policy mechanisms for doing so. Toward that end, this paper also begins to fill an obvious void.

Risk, barriers to technology, and market failure

Risk and closely related difficulties appropriating returns create barriers to technology, and as a result of these barriers to technology there will be market failure leading to an underinvestment in or underutilization of technology. Much of the market failure literature focuses on investments into the creation or production of technology (e.g. R&D). Equally relevant, although often overlooked, are investments for the use and application of others' technology (Tassey 1995, 1997; Link and Scott 1998a, b).

Risk measures the possibilities that actual outcomes will deviate from the expected outcome, and the shortfall of the private expected outcome from the expected return to society reflects appropriability problems. The technical and market results from technology may be very poor, or perhaps considerably better than the expected outcome. Thus, a firm is justifiably concerned about the risk that its R&D investment will fail, technically or for any other reason. Or, if technically successful, the R&D investment output may not pass the market test for profitability. Further, the firm's private expected return typically falls short of the social expected return.

The expected outcome is the measure of central tendency for a random variable's outcome. Risk is sometimes quantified as the variance of the probability distribution for a random variable's outcome—here, the technical outcome of R&D or the market outcome of the R&D output is the random variable—although other aspects of the probability distribution may affect risk as well. Thus, the contribution to a firm's overall exposure to risk associated with a particular investment will be different depending on the collection of projects in the portfolio. In that sense, a large firm, with a diversified portfolio of R&D projects, might find a particular project less risky than a small firm with a limited portfolio. Similarly, society faces less risk than the individual firm, large or small, because society has, in essence, a diversified portfolio of R&D projects and that diversification reduces risk (because of bankruptcy costs or managers' firm-specific human capital) that the decision makers in individual firms will consider. As risk is reduced to society, overall outcomes become more certain. Further, for each particular technological problem, society cares only that at least one firm solves the technical problems and that at least one is successful in introducing the innovation into the market. The individual firm pursuing the technical solution with R&D and then trying to market the result will of course face a greater risk of technical or market failure.

Facing high risk—both technical and market risk not faced by society—or simply because society has a longer time horizon than the decision makers of individual firms, a private firm discounts future returns at a higher rate than does society. Therefore, the private firm values future returns less and, from society's perspective, will invest too little in R&D. Put another way, the higher the risk the higher the hurdle rate or required rate of return for a project. Thus, when social risk is less than private risk, the private firm will use a hurdle rate that, from society's perspective, is too high. Socially useful projects will accordingly be rejected. Further, when the firm's expected return falls short of society's expected return, the firm has less future returns to value than society does, and again, underinvestment will result.

Market failure, resulting from risk and the closely related difficulties of appropriating returns to investments in technology—R&D specifically—will lead to a divergence between private and social benefits. The social rate of return will be greater than the private rate of return; there are, of course, expected or *ex ante* returns. This is illustrated below in terms of Figure 1, following Jaffe (1998). The purpose of this simple heuristic device is to characterize private sector projects with returns not only less than the expected social returns hut also less than the private hurdle rate for projects normally undertaken by the firm. The figure illustrates such private projects in terms of their technology focus, and this then provides a useful device for characterizing the appropriateness of private sector support directly through partnerships as opposed to indirectly through fiscal tax incentives.

The social rate of return is measured on the vertical axis of Figure 1 along with society's hurdle rate on investments in R&D. The private rate of return is measured on the horizontal axis along with the private hurdle rate on investments in R&D. A 45 degree line (long dashed line) is imposed on the figure under the assumption that the social rate of return from an R&D

investment will at least equal the private rate of return from that same investment. The three illustrative projects discussed below are labeled projects A, B, and C.

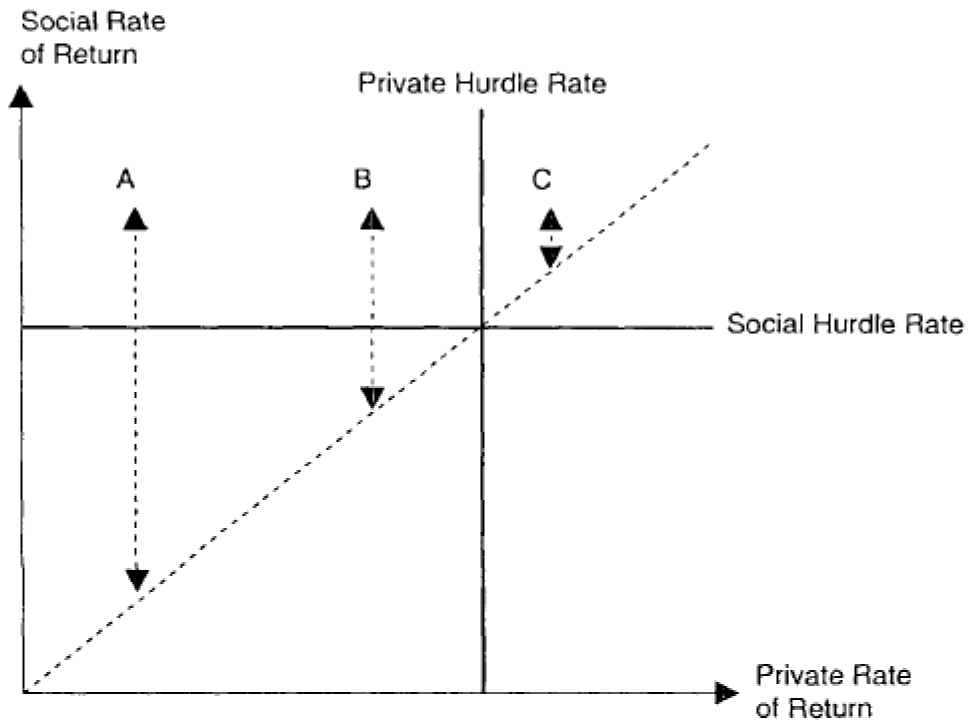

Figure 1. Gap between social and private rates of return to R&D projects

For project C, the private rate of return exceeds the private hurdle rate, and the social rate of return exceeds the social hurdle rate. The gap (short vertical dashed line) between the social and private rates of return reflects the spillover benefits to society from the private investment. However, the inability of the private sector to appropriate all benefits from its investment is not so great as to prevent the project from being adequately funded by the private firm. In general, then, any R&D project with a private rate of return to the right of the private hurdle rate and on or above the 45 degree line is not a candidate for public support because, even in the presence of spillover benefits, the R&D project will be funded by the private firm.

Consider projects A and B. The gap between social and private returns is larger than in the case of project C; neither project will be adequately funded by the private firm. To address this market failure the government has two alternative policy mechanisms. It can use a tax policy to address the private underinvestment in R&D or it can rely on public/private partnerships as a direct funding mechanism.

If the private return to project B is less than the private hurdle rate because of the risk and uncertainty associated with R&D in general, then tax policy may be the appropriate policy mechanism to overcome this underinvestment. Risk is inherent in a technology-based market, and there will be certain projects for which the rewards from successful innovation are too low for private investments to be justified. Tax policy, such as the R&E tax credit, may in these situations reduce the private marginal cost of R&D sufficiently to provide an incentive for the project to be undertaken privately. For projects like project B, a tax credit may be sufficient to increase the expected return so that the firm views the post-tax credit private return to be sufficient for the project to be funded.

However, for projects like project A, a tax credit may be insufficient to increase the expected return so as to induce the private firm to undertake the project. In such a case, which could include for example projects expected to yield an innovative project that would be part of a larger system of products and thus even if technically successful the product might not interoperate or be compatible with other emerging products, direct funding rather than a tax credit may be the appropriate policy mechanism.

A priori, it is difficult to generalize about the way that any one firm's under-funded projects will be distributed in the area to the left of the firm's private hurdle rate. However, some generalizations can be made about the portfolio of private sector firms' projects in general. For those R&D projects, like project B, for which the firm will appropriate some returns but for which the overall expected return is slightly too low, a tax credit may be sufficient to increase the expected return to the point that the expected return exceeds the private hurdle rate. Such projects may likely be of a product or process development nature and are likely to be a part of the firm's ongoing R&D portfolio of projects. For those R&D projects, like project C, for which the firm has little ability to appropriate returns even if the marginal cost of the project is reduced through an R&D tax credit, say, the firm may not respond to such an R&D tax policy but may respond to a direct funding policy mechanism. Such projects may likely be of a generic technology nature, that is technology from which subsequent market applications are derived and that enable downstream applied R&D to be undertaken successfully. Generic technology and the associated research process represent the organization of knowledge into the conceptual form of an eventual application and the laboratory testing of the concept. Generic technology draws on the science base, but unlike scientific knowledge it has a functional focus.

Thus, the economic rationale for public/private partnerships is that such partnerships represent one direct funding R&D policy appropriate to overcome market failure and that they are necessary, compared to fiscal tax incentives, when the R&D is generic in character.

A TAXONOMY OF PUBLIC/PRIVATE PARTNERSHIPS

As discussed above, the term "partnership" is used in this paper to refer to any innovation-based relationship that involves public and private resources, where resources refer to financial resources, research resources, and infrastructure resources.

There are a number of useful ways to categorize public/private partnerships. For example, Coburn (1995) classifies co-operative technology programs or partnerships in terms of the benefits and services they offer to industry. Toward that end, five so-called functional categories are posited:

(1) Technology Development: research and applications for new or enhanced industrial products and processes.

(2) Industrial Problem Solving: identifying and resolving company-level industrial needs through technology and best-practice applications.
(3) Technology Financing: public capital or help in gaining access to private capital.
(4) Start-up Assistance: aid to new small technology-based businesses.
(5) Teaming: help in forming strategic partnerships and alliances.

Alternatively, the Office of Technology Policy (1996) classifies public/private partnerships along a time spectrum so as to illustrate and emphasize that public/private partnerships have evolved from a relationship wherein the government was merely a customer of private research to a relationship wherein the government is a partner in research. In other words, the Office of Technology Policy's taxonomy is one that stresses the evolution of the public role in public/private partnerships.

In this paper, public/private partnerships are alternatively and uniquely classified in terms of the economic objective of the partnership. Public/private partnerships can be formed to accomplish at least three broad, although not necessarily independent, economic objectives:

(1) Public/private partnerships can exist to leverage the social benefits associated with federal R&D activity.
(2) Public/private partnerships can exist to enhance the competitive position of industry in the global marketplace.
(3) Public/private partnerships can exist to leverage industrial R&D to meet military or defense needs.

Table 1 sets forth a taxonomy of public/private partnerships in terms of the economic objective for creating the partnership as well as the public resources marshaled to facilitate the objectives of the partnership. Not surprising, because public/private partnerships are a direct funding policy mechanism, the public sector brings financial resources to the relationship. But as well, the history of partnerships in the United States reveals that infrastructural resources are also provided by the government. Infrastructural resources refer to changes in the research climate or environment (such as a change in the antitrust environment that thereby encourages the formation of research joint ventures as an infrastructural resource) in which the partnership exists. It should also be emphasized, as is noted in Table 1, that public research resources are only an integral part of the public resources brought to a public/private partnership that leverage federal R&D. The absence of this characteristic in the other two partnership areas should not be interpreted to suggest that the research undertaken in federal laboratories, including federally sponsored university laboratories for example, does not have an important economic objective and does not spillover to enhance industry. Rather, it is extremely important research, and it enhances the efficiency with which the private sector conducts its applied research and development. Such public research is simply not the most fundamental aspect of public resources that are brought into the types of public/private partnerships.

Table 1. Taxonomy of public/private partnerships

Aspect of direct funding by the public sector	Economic objective		
	Leverage federal R&D	Enhance industrial competitiveness	Leverage industrial R&D
Financial resources	yes	yes	yes
Research resources	yes	no	no
Infrastructural resources	yes	yes	yes

Expenditures supporting public/private partnerships

While public/private partnerships, in one form or another, have long been an important aspect of technology policy in the United States, surprisingly there is not a systematic set of data from which to quantify resources allocated to such relationships much Jess to estimate trends in such direct federal support. Table 2 was constructed using extant budget information from a variety of sources. As discussed in this section, the information in this table is not intended to represent all federal resources allocated to public/private partnerships. Although this table perhaps represents one of the most systematic accountings of such direct federal support, it should be viewed only as an initial approximation. For example, absent from the table are public resource allocations in National Cooperative Research Act (of 1984) research joint ventures by public research partners.

Table 2. Federal R&D funding of public/private partnerships ($M)

	1993	1994	1995	1996
Total federal funds for R&D[1]	$60,301	$60,224	$61,050	$60,700
Small Business Innovation Research (SBIR) Program[2]	698	718	865	900
CRADAs[3]	407	588	752	916
Advanced Technology Program (ATP)[4]	68	199	341	491
NCRA RJVs	nda	nda	nda	nda
SEMATECH[5]	95	90	89	90
Dual-Use Technology Program[3]	882	1,441	1,429	1,454

Notes: 1 National Science Board (1996), Appendix Table 4-4.
2 National Science Board (1996), Appendix Table 4-15 and unpublished National Science Foundation data, and Carr (1997).
3 Office of Management and Budget data as reported in Carr (1997).
4 NIST Annual Budget (gopher://potomac.nist.gov:7346/0/.docs/.budgct/).
5 SEMATECH Annual Reports.
"nda" means that no expenditure data are available.

To put the information in Table 2 in perspective, consider some background statistics. Total federal funds for R&D were in 1995, for example, $61,050M. Total national expenditures on R&D in that year (federal plus funds from industry, universities and colleges, and other nonprofit organizations) were $169,100M (National Science Board 1996). Thus, federal expenditures accounted for 36 percent of total R&D. Also in 1995, total R&D expenditures by federal laboratories were $26,578M (GAO 1996a). Thus, nearly 44 percent of total federal funding for R&D was budgeted to the federal laboratory system, or 16 percent of total national expenditures on R&D was budgeted to the federal laboratory system.

Listed in Table 2 are six public/private partnership areas that will be discussed in greater detail below. They are listed in Table 2 by name here only to identify the partnerships to which the dollar expenditures being discussed herein are associated. In 1995, at least $3,476M of public funds were allocated to the five public/private partnerships listed, and in 1996 that amount was $3,851M. Public funds allocated to the public/private partnerships listed as a percentage of total funded federal R&D, were 5.7 percent in 1995 and about 6.3 percent in 1996 (using the 1995 base). This percentage has increased from 3.6 percent in 1993, to 5.0 percent in 1994, to the 6.3 percent estimate for 1996.

Again, it must be emphasized that these percentages are based on data from only five programs. But, to put the magnitude of these direct funding public expenditures in a policy perspective, it has been estimated that the annual cost of the R&E tax credit in terms of credits claimed has been approximately $ 1 ,600M (OTA 1995). Thus, from an expenditure side, over twice as many federal dollars have, at least in recent years, been allocated to support private sector research *directly* through partnerships (e.g. direct funding) as opposed to *indirectly* through fiscal tax incentives.

This 2-to-l ratio does not at all imply that the economic benefits associated with one R&D policy mechanism are greater compared to the other. In fact, the extant economic literature is conspicuously void of empirical studies related to the magnitude of social benefits that any sector receives through public/private partnerships, and there is at best preliminary evidence regarding the social benefits associated with the R&E tax credit (OTA 1995).

INSTITUTIONAL HISTORY OF PUBLIC/PRIVATE PARTNERSHIPS

Brief early history of cooperative technology development[2]

One can trace the origins of a broadly defined cooperative technology development policy, or of technology partnerships, in the United States at least to the Lincoln Administration. In 1862, the Morrill Act established what was known as the land-grant college system. The Act created a partnership between the federal and state governments to cooperate with the private sector in technology development. That Act charged states to develop colleges to offer curricula in agricultural and mechanical arts. Then, in 1887, the Hatch Act provided resources for a system of state agricultural experiment stations that would be under the auspices of land-grant colleges and universities. A partnership among the various levels of government was established by the Smith-Lever Act of 1914. The Cooperative Agricultural Extension Service was charged to deliver the practical benefits of research to citizens though an extension service.

Recent history of public/private partnerships[3]

According to Carr (1995: 11):

> Until the end of the 1970s, the philosophy behind the dissemination of federally-funded research was that if the public paid for the research, the resulting intellectual property should be made equally available to all interested parties.

---

[2] This section draws from Carr (1995).
[3] This section draws from Office of Technology Policy (1996).

The 1970s and 1980s witnessed many foreign competitors begin to successfully challenge the long-standing dominance of the United States not only in world markets but also in the domestic market. It soon became clear to public and private policy leaders that a change in its philosophy of federal R&D support was needed; traditional processes of public/private technology development needed to be re-examined. The Office of Technology Policy (1996) puts this change in public policy mindset into perspective, and it posits three important reasons for such a re-examination of public policy:

(1) Global competitors were better able to appropriate the output of US basic and mission-oriented research as their technical sophistication grew.
(2) Traditional public sector mechanisms of technology development, transfer, and development took too long in an era of accelerating private sector development.
(3) US government R&D represented a declining share of world R&D as globally competing nations increased their public funding; hence, the marginal benefits to industry for additional public moneys (allocated in the same manner as historically) declined.

Stated alternatively, but maintaining the same general theme, Link and Tassey (1987: 4, 131) reflect on what were then (early 1980s) recent changes in the competitive environment of US industry:

> Today, there is a new order of competition in the world. An inescapable element of the competition is technology ... With the advent of technology-based economies [throughout the world,) the increase in the number of world competitors has been greater than the increase in the size of the world market. What has resulted from this is a significant shortening of technology life cycles ... As such, effective long-run competitive strategies will have to deal explicitly with technology ... [C]ompetitive survival will depend on technology-based strategies. These strategies will have to evolve from new philosophies about interdependence ... The importance of interdependence arises from the need of a domestic industry to rapidly and efficiently develop complex technological elements from which specific applications (innovations) are drawn for competitive activity ... [Accordingly), government must expand and adapt its role ... with industry for more effective joint planning in research.

Beginning with legislation in 1980, as summarized only briefly in this section, a new era in federal technology policy began. This new era was based on the belief that the global competitiveness of US firms can be enhanced through legislation to bolster the commercial impact of federal R&D investments. As such, using the terminology of the Office of Technology Policy (1996: 26), "a new paradigm for public/private technology partnerships emerged". The new paradigm can be described by the schematic in Figure 2.

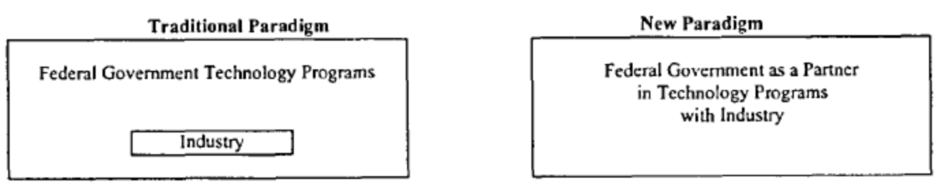

Figure 2. New paradigm for public-private technology partnerships
Note: Adapted from Office of Technology Policy (1996: 34)

Prior to the 1980s, the federal government viewed itself, as did industry, as a customer for industry's technology development programs. As Figure 2 illustrates, industry was the research core of the federal government's research program, but the federal government was not a part of industry's core research. Beginning in the early 1980s that view changed, and the federal government began to view itself as a partner with industry in joint technology development programs, although its collaboration was primarily in terms of financial rather than research resource support.

1. The first major piece of federal legislation that was intended to leverage public/private technology development within this new paradigm was the Stevenson-Wydler Technology Innovation Act of 1980 (P.L. 96-480). This Act was predicated on the premise that federal laboratories embody important and industrially useful technology. Accordingly, each federal laboratory was mandated to establish an Office of Research and Technology Application (OTRA) to facilitate the transfer of public technology to the private sector. Such facilitation was part of the authority given to the Department of Commerce under the Act, namely:

> to enhance technological innovation for commercial and public purposes ... including a strong national policy supporting domestic technology transfer and utilization of science and technology resources of the federal government.

2. The University and Small Business Patent Procedure Act of 1980 (P.L 96-517), also known as the Bayh-Dole Act, reformed federal patent policy thereby providing increased incentives for the diffusion of federally funded innovation results. More specifically, universities, nonprofit organizations, and small businesses were permitted to obtain title to innovations they developed with the use of governmental financial support, and the Act allowed federal agencies to grant exclusive licenses to their technology to industry.

In a broad sense, Stevenson-Wydler and Bayh-Dole institutionalized public/private partnerships through the more efficient transfer of federally developed technology to the private sector. This represents a form of public infrastructural support to industry.

3. The Small Business Innovation Development Act of 1982 (P.L. 97-219) required that federal agencies provide special funds to support small business R&D that complemented the funding agency's mission. This was called the Small Business Innovation Research (SBIR) program.

Based on the premise, as stated in the Act, that "small business is the principle source of significant innovation in the Nation", and small businesses are "among the most cost-effective performers of research and development and are particularly capable of developing research and development results into new products", the Act lists its purposes for, among other things, establishing the SBIR program:

(1) to stimulate technological innovation;
(2) to use small businesses to meet federal research and development needs;

(3) to foster and encourage participation by minority and disadvantaged persons in technological innovation; and
(4) to increase private sector commercialized innovations derived from federal research and development.

The Small Business Innovation Research Program Reauthorization Act of 1992 gave reauthorization to the SBIR program because the program has "effectively stimulated the commercialization of technology development through federal research and development, benefiting both the public and private sectors of the Nation".

4. The National Cooperative Research Act (NCRA) of 1984 (P.L. 98-462) has two main objectives. The first objective was to establish a rule of reason for evaluating the antitrust implications of research joint ventures (RJVs) on an individual case basis and to limit potential liability to actual rather than treble damages as is more common under antitrust law.

The NCRA was amended by the National Cooperative Research and Production Act (NCRPA) of 1993 (P.L. 103-42). The purpose of this amendment was to broaden the scope of the original NCRA to include production activities as well as research in general (Link 1996b).

5. The Trademark Clarification Act of 1984 (P.L. 98-620) set forth new licensing and royalty regulations thereby taking technology from federally funded facilities into the private sector. Specifically, the Act permitted government-owned, contractor-operated (GOCO) laboratories to make decisions regarding which patents to license to the private sector, and contractors could receive royalties on such patents.

6. The Federal Technology Transfer Act of 1986 (P.L. 99-502), the last major piece of federal legislation designed to leverage the economic impact of federal investments in R&D, amended the Stevenson-Wydler Act (Office of Technology Policy 1996). Among other things, the Act made explicit that technology transfer was the responsibility of all federal laboratory scientists and engineers. Specifically, it authorized cooperative research and development agreements (CRADAs) to be established between public/private research organizations.

This Act was later amended by the National Competitiveness Technology Transfer Act of 1989. The 1989 Act expanded the definition of federal laboratory from one that is government-owned and government-operated (GOGO) to one that is a GOCO. The implication of this Act is to allow GOCOs to enter into CRADAs.

7. The Omnibus Trade and Competitiveness Act of 1988 (P.L. 100-418) not only changed the name of the National Bureau of Standards to the National Institute of Standards and Technology, but also facilitated the ability of Congress to enact two so-called direct competitiveness programs-the Advanced Technology Program (ATP) and the Manufacturing Extension Partnership (MEP). The MEP is a partnership in name more than in research mission. MEPs assist small- and medium-sized manufacturers assess their technology needs and then facilitate its purchase and implementation. The American Technology Preeminence Act of 1991 (P.L. 102-245) later clarified the mission of the ATP.

The goals of the Advanced Technology Program (ATP) at NIST, as stated in its enabling legislation, the Omnibus Trade and Competitiveness Act of 1988, and modified by the American Technology Preeminence Act of 1991, are to assist US business in creating and applying the generic technology and research results necessary to:

(1) commercialize significant new scientific discoveries and technologies rapidly; and
(2) refine manufacturing technologies.

As restated in the *Federal Register* on July 24, 1990:

> the ATP ... will assist U.S. businesses to improve their competitive position and promote U.S. economic growth by accelerating the development of a variety of pre-competitive generic technologies by means of grants and cooperative agreements.

8. Finally, the Defense Conversion, Reinvestment, and Transition Assistance Act of 1992 (P.L. 102-484) created an infrastructure for dual-use partnerships. Through Technology Reinvestment Project (TRP) partnerships, the Department of Defense was given the ability to leverage the potential advantages of advanced commercial technologies to meet the Department's needs. TRP partnerships speed the development of a commercial technology so that a domestic market that is self sustaining, will develop itself sooner than would otherwise be expected; TRP partnerships then focus the identified commercial technology development in a way that simultaneously (e.g. dual use) meets the needs of industry and military. TRP partnerships benefit the defense sector first and foremost; spillover benefits to industry occur in the form of more rapid development of selected technologies. In 1996, TRP partnerships were subsumed under the Dual-Use Applications Program.

SELECTED PUBLIC/PRIVATE PARTNERSHIP AREAS

This section reviews each of the six public/private partnership areas listed in Table 2 above. Each partnership is discussed below in an order reflecting their economic objective as set forth in the taxonomy in Table l:

(1) to leverage federal R&D (SBIR Program and CRADAs);
(2) to enhance industrial competitiveness (ATP, NCRA research joint ventures, and SEMATECH);
(3) to leverage industrial R&D (dual-use technology partnerships).

And, each partnership area is referenced back to the taxonomy presented in Table 1.

SBIR program

As discussed above, the Small Business Innovation Development Act of 1982 authorized the SBIR program, and the program was then again reauthorized by the Small Business Research and Development Enhancement Act of 1992. Eleven federal agencies participate in the program. The five largest agencies being the Department of Defense, the National Aeronautics and Space

Administration, the Department of Health and Human Services and its National Institute of Health, the Department of Energy, and the National Science Foundation.

The enabling legislation required each federal agency with an external R&D budget greater than $100M to set aside a stated percentage which was increased to 1.25 percent in 1986. When reauthorized in 1992, that percentage was increased to not less than 1.5 percent for the years 1993 and 1994, not less than 2.0 percent for the years 1995 and 1996, and not less than 2.5 percent for 1997 and subsequent years.

SBIR awards are made in three phases. Phase I awards are designed to determine the technical merits of an idea. These awards last about 6 months to 1 year. Phase II awards, which last about 2 years, are to further develop the ideas in Phase I, if technically feasible. Phase III awards are more selective and generally involve follow-on contractual work with the funding agency.

It is the opinion of the GAO (1996c) that the quality of research performed under SBIR sponsorship appears to have kept pace with the financial expansion of the program, as has the level of competition. Proposals awarded to proposals received has consistently ranged between about 8 percent from the Department of Energy to about 28 percent from the National Institute of Health.

Table 3 shows the results of efforts to commercialize new products as a result of SBIR support. Clearly, over time, an increasing percentage of SBIR projects are being commercialized.

Table 3. Commercial success of SBIR awards

Years after Phase II award	Percent commercialized or near commercialization	Percent still pursuing commercialization
4	17.7	9.6
5	22.4	10.9
6	26.8	10.0

Note: Adopted from OTP (1996).

With reference to the taxonomy of public/private partnerships in Table 1, the SBIR program's goal is to leverage the mission-oriented R&D of the financing federal agency. Obviously, each agency is supplying financial rather than research resources to the program. But, the SBIR program also provides infrastructural resources in the form of a unique and special funding environment. In particular, the program targets small- and medium-sized enterprises and minority enterprises for financial assistance.

There have been several survey-based studies related to the SBIR program. Representative of this group of scholars is the study by Berger *et al.* (1992). They attempt to describe, as opposed to evaluate from an economic perspective, the SBIR program (p. 28):

> ... this study [was] one of the first attempts to assess the relationship between government R&D products [e.g. financial resources in terms of Table 1 of this paper] and the resultant commercialization of the developed technology.

Based on information collected from samples of Phase II awardees in fiscal years 1988, 1989, and 1990, funded by one of 11 major government agencies, Berger *et al.* conclude that SBIR awardees were exhibiting a range of commercialization activities (see Table 3). More specifically:

(1) the commercialization that is taking place is doing so in niche markets, so spectacular growth is not expected;
(2) employment has increased in these companies due to SBIR funding, so it remains to be seen if there will be significant employment effects once Phase II is completed;
(3) forecasts arc that over 30 percent of SBIR Phase II projects should eventually reach commercialization, a far greater percentage than was envisioned when the program began.

Cooperative R&D Agreements

Partnerships between industry and federal laboratories using a CRADA mechanism were made possible by the Federal Technology Transfer Act of 1986. While viewed by most as a technology transfer vehicle rather than a vehicle for direct funding of R&D, these mechanisms are conceptualized for the purposes of this paper as an example of a public/private partnership that has an indented goal of leveraging the capabilities of federal R&D and thereby increasing the competitiveness of private R&D through transfers of knowledge.

Table 4 shows that the use of CRADAs as an infrastructural mechanism to facilitate the creation of the public/private partnership has increased exponentially over time. The expenditure data in Table 2 show that funding of partnerships through CRADAs has also increased over time. Such federal funding takes the form not of a direct grant, but rather in-kind public resource expenditures (e.g. labor time) directed toward the CRADA-based research and, sometimes, the private sector's use of federal laboratory research resources to facilitate the research program.

Table 4. Active cooperative R&D agreements: 1987–1994

Year	Number
1987	34
1988	98
1989	271
1990	460
1991	731
1992	1,250
1993	1,847
1994	2,607

Source: Office of Technology Policy (1996).

In 1994, the GAO conducted a preliminary evaluation of the benefits associated with cooperative R&D arrangements. Based on detailed case studies of ten representative CRADAs, the GAO (1994) concluded that:

(1) CRADAs offered opportunities for federal laboratories and industry to collaborate on research while still meeting their missions;

(2) technology from federal laboratories was transferred to the private sector effectively, and this resulted in commercialized new products;
(3) federal and industrial R&D programs were advanced in terms of scientific capabilities;
(4) some CRADAs demonstrated a potential for long-term improvements in the economy, and overall health of the country.

With reference to the taxonomy of public/private partnerships in Table 1, the goal of CRADA mechanisms is also to leverage the capabilities of federal R&D. Through CRADAs, the public sector provides financial resources in the form of in-kind labor, research resources in the form of access to specialized equipment in federal laboratories, and infrastructure resources by the very nature of the partnership mechanism.

To date, this GAO study represents the state-of-the-art. There has not yet been a critical evaluation of CRADA activity in terms of their effectiveness as a public/private vehicle for leveraging the capabilities of federal R&D.

Advanced Technology Program

The ATP is a public/private partnership designed to enhance the competitiveness of industry. The enabling legislation, as discussed above, is explicit about that fact:

> The ATP ... will assist U.S. businesses to improve their competitive position and promote U.S. economic growth by accelerating the development of a variety of precompetitive generic technologies by means of grants and cooperative agreements.

Since its inception in 1990, as authorized by the Omnibus Trade and Competitiveness Act of 1988, ATP has held eight open (to all areas of technology) competitions and five focused (to a pre-defined technology area) competitions. From these competitions, 288 projects have been funded.

While it is premature to judge the competitiveness consequences associated with ATP funding, there is initial evidence, based on case studies and survey information, that ATP has (NIST 1995):

(1) been successful in encouraging high-risk R&D projects that would not otherwise have been pursued;
(2) helped US industry compete in time-critical markets by accelerating their research agenda and thereby reducing time to market;
(3) created new commercial opportunities for funded companies that are successful in their R&D efforts;
(4) promoted economic growth by creating an environment conducive for the permanent creation of selected new jobs.

With reference to the taxonomy of public/private partnerships in Table 1, the explicit goals of the ATP are to enhance competitiveness by underwriting selected research projects. Thus, by design, ATP represents a program for direct funding of private sector research through public sector financial resources. In addition, limited infrastructural resources are allocated to this program as well. ATP will, through its peer review of all proposals, marshal public resources to advise applicants about the scientific and technical merit of their research. This is a valuable public role because it affords companies that might not otherwise be able to obtain such advice, focused guidance even if their proposed project is not funded, and this guidance may facilitate a later re-application to the ATP or to other funding sources. Still, in the case of the ATP, federal financial resources far outweigh the use of federal infrastructural resources.

The ATP relies in part on metrics-based case study evaluations of its funded projects.[4]' Although projects began to be funded only in 1991, and the 11 which began in that year have just completed their research in 1996. Nevertheless, two of several completed case evaluations to date of an ATP-funded and completed project are by Link (1998a, c), although other case studies are underway under the sponsorship of ATP. Link's (1998a) end-of-project assessment of the Printed Wiring Board Research Joint Venture Project, for example, based on survey results, is that, among other things:

(1) of the 62 research tasks completed, about one-half would not have been done at all in the absence of ATP funding, and those that would have would have been delayed by at least one year and would have cost the participating companies an additional $35.5 million to complete the project at the same technical level;
(2) members of the research joint venture are, because of the research results, becoming more competitive in certain segments of the world market for printed wiring board.

NCRA research joint ventures

Unlike the ATP, research joint ventures formed as a result of the National Cooperative Research Act (NCRA) of 1984, benefited more from federal infrastructural resources than federal financial resources.

The environment created by NCRA and its 1993 amendment, the National Cooperative Research and Production Act (NCRPA), facilitated the formation of research joint ventures with assurances that any suspected antitrust violation will be judged on a case-by-case basis, and any related damage will be actual rather than treble. This is not to say that partners form research joint ventures with the intent of "hiding" purposeful antitrust violations, rather NCRA and NCRPA created an environment conducive to disclosure and therefore conducive to the formation of research partnerships.

Table 5 shows the number of research partnerships formed, by year, since the passage of the NCRA. And, Table 6 shows the composition of the partnerships. Notable in Table 6, at least for the purposes of this paper, is that federal organizations, federal agencies plus federal laboratories, are the dominant external partner (compared to other non-private sector participants such as universities for example) in these research relationships (Leyden and Link 1999).

---

[4] ATP was one of the first federal research programs to establish a general evaluation plan. ATP's management realized early on that it would take years before social economic benefits associated with the program could be identified must less quantified. Nevertheless, management set forth an agenda for assembling and collecting relevant information as pan of a multifaceted evaluation plan. See Link (1996a) and Ruegg (1998).

Table 5. Formation of NCRA research joint ventures, by year

Year	Number of RJVs
1985	50
1986	17
1987	26
1988	31
1989	27
1990	46
1991	61
1992	59
1993	73
1994	63
1995	115
1996	97
Total	665

Note: Data are from the CORE database (Link 1996b).

Table 6. Formation of NCRA research joint ventures with public partners, by year

Year	Percent of RJVs with public organization as a research partner
1985	18
1986	6
1987	8
1988	29
1989	19
1990	7
1991	7
1992	17
1993	15
1994	24
1995	30
1996	23

Note: Data are from the CORE database (Link 1996b).

While trends in NCRA research joint venture formation are not indicative of economic impacts so associated, the fact that the number of research partnerships, especially public/private (meaning that there is a federal organization as a member) partnerships, has increased over time is indicative of the fact that some benefits must be perceived by the public sector and by the private sector as a result of the federal organization being in the partnership. Theorists have modeled such benefits, as for example research cost savings, but to date no systematic empirical evaluations have been conducted on the benefits that members of such partnerships receive or on the spillover benefits to the related industry(ies).

With reference to the taxonomy of public/private partnerships in Table 1, the 1984 NCRA and its 1993 amendment provided infrastructural resources in the form of a more conducive environment for the joint conduct of research.

SEMATECH

As discussed, with the passage of the NCRA in 1984, Congress explicitly recognized the importance of collaborative research relationships. The first, and perhaps one of the more notable research joint ventures that began shortly after the passage of the NCRA was SEMATECH (SEmiconductor MAnufacturing TECHnology). Established in 1987 as a not-for-profit research consortium, its original mission was to provide a pilot manufacturing facility where member companies could improve their semiconductor manufacturing process technology. Its establishment came after the Defense Science Board recommended direct government subsidy to the industry in a 1986 report commissioned by the Department of Defense. It was thought that SEMATECH would be the US semiconductor industry's response to the Japanese government's targeting of their semiconductor industry for global domination (Erdilek 1989). Although the mission of SEMA TECH has evolved over time, it generally has defined its mission around solving the technical challenges presented by sustaining a leadership position for the United States in the global semiconductor industry. Since its beginning, it has received Defense Department funding although funding ended at the end of fiscal year 1997 at the request of SEMATECH members.

SEMATECH sponsors three types of research projects. Joint Development Projects are part of a program in which a SEMATECH team of researchers partners with an external equipment supplier to develop a new tool, material, or process that supports phase requirements of future generation technology. Equipment Improvement Projects are designed to improve existing manufacturing equipment or systems from the perspective of competitive manufacturing. SEMATECH improvement projects reside at SEMATECH (rather than at a manufacturer's facility) and are short term and narrowly focused on production issues.

In contrast to NCRA research joint ventures in which the principle public resource brought forward to facilitate such partnerships is infrastructure in terms of creating an antitrust-friendly environment, SEMATECH represents what could be viewed in terms of the public/private partnership taxonomy in Table 1, as a "purer" example of direct financial resource support to achieve global competitiveness in a selected industry.

While there has not been a systematic evaluation of the impact of SEMATECH on the semiconductor industry as a whole, one focused investigation of the economic benefits members receive from their participation in the consortium was conducted by Link *et al.* (1996). They concluded from their detailed analysis of a sample of 11 representative and completed SEMA TECH projects that:

(1) companies benefited from sharing research results and that this sharing environment would not have existed without public funds to initiate the organization;
(2) in terms of member-specific benefits compared to member-specific costs, the ratio is approximately $ 3-to-$1.

Dual-use applications program

In order to enable the Department of Defense to take full advantage of, and in many cases direct toward its military and defense needs, the research and technological capabilities of industry, Congress authorized the development of a direct funding mechanism called the dual-use technology partnership. After Congress approved the concept in 1990, and after the passage of the Defense Conversion, Reinvestment, and Transition Assistance Act of 1992, the Technology Reinvestment Project (TRP) began.

TRP is the Administration's so-called dual-use vehicle. It is an inter-agency program for grants to industry in pursuit of dual-use R&D and technology (Chapman 1994). Dual-use R&D and dual-use technology are those that are expected to be useful to both the military as well as to industry for commercial application.

TRP's initial strategy was to cost-share R&D projects in order to develop dual-use technology needed by both industry and the military (ARPA 1995). Department of Defense funding ensures that industry R&D can be directed toward the Department's special needs. Because this is technology that industry is expected to commercialize, private firms that receive TRP support encumber at least 50 percent of the R&D cost. The TRP strategy of dual-use partnerships:

(1) leverages emerging industrial technology;
(2) embeds defense technology.

In 1996, TRP was subsumed under the Dual-Use Applications Program. Its mission is broader than TRP's; its mission is to prototype and demonstrate new approaches for leveraging commercial research, technology, products, and processes into military systems.

Dual-use technology partnerships, in terms of the taxonomy of public/private partnerships in Table 1, leverage industrial R&D for the benefit of the military. Certainly public financial resources are utilized in this program since the military funds a minority portion of the R&D, but public infrastructure resources are also involved in that a specialized procurement environment (i.e. procurement process) is in place to identify and fund in an expeditious manner identified technologies without the bureaucracy of competitive bids.

A large number of focused studies have been conducted related to TRP. These studies almost exclusively have been case oriented in the sense that the objective of the study was to document that dual-use technology had in fact been developed (Institute for Defense Analysis 1994). No studies have been conducted on TRP, in particular, or on dual-use programs, in general, from an economic impact perspective.

Table 7. Taxonomy of public/private partnerships

	Economic objective		
Aspect of direct funding by the public sector	**Leverage federal R&D**	**Enhance industrial competitiveness**	**Leverage industrial R&D**
Financial resources	SBIR	ATP	Dual-Use
	CRADAs	SEMATECH	
Research resources	CRADAs	—	—
Infrastructural resources	SBIR	NCRA RJVs	Dual-Use
	CRADAs	SEMATECH	

The six public/private partnership areas are re-summarized in Table 7 in terms of the public/private partnership taxonomy in Table 1.

INITIAL EVALUATION OF PUBLIC/PRIVATE PARTNERSHIPS

As the new paradigm for public/private relationships in technology approaches being two decades old, the Office of Technology Policy (1996) made an initial assessment of public/private partnerships. Each of their findings, albeit very general, and each subsequent recommendation, albeit non-operational for the most part, are summarized in this section. Attention is given to these findings and recommendations not because of their direct usefulness to nations as a *per se* template for action, but because they do represent one of the few, if not the only, official US governmental statement on this topic. This uniqueness has merit and can, depending on the circumstances, offer a road map for what others might do.

Findings regarding public/private partnerships

The Office of Technology Policy (1996) arrived at five general findings about public/private partnerships on the basis of extensive discussions with private sector partners in such relationships. The Office finds the following:

(1) Technology partnerships play an important role in fostering US competition by maximizing the commercial impact and value to society of public investments in government-funded basic research and mission-related R&D, and by working in partnership with the private sector to develop high risk enabling technologies and speed their diffusion.
(2) Technology partnerships enhance the effectiveness of government mission-related R&D because, through partnerships, US agencies gain access to and leverage (i) advanced commercial technologies, (ii) private sector production efficiencies, and (iii) larger markets thereby enabling the government to fulfill its mission requirements more effectively and at a lower cost.
(3) The US private sector strongly supports federal technology partnership programs.
(4) Federal technology partnerships are part of a larger set of private sector priorities for stimulating innovation and competitiveness by reducing the high cost and technical risks that can impede innovation.
(5) Technology partnership programs benefit the US economy in a variety of ways, including but not limited to profits, jobs, and new products.

Table 8. Evaluation findings on public/private partnerships

	Type of evaluation conducted	Estimated economic impacts
SBIR	surveys	more and faster commercialization of products
CRADAs	case studies	transfer of technologies to private sector
ATP	multifaceted, including case studies	research cost savings and increased competitiveness
NCRA RJVs	theoretical	research cost savings to participants
SEMATECH	limited case studies	research cost savings to members
Dual-Use	case studies	that dual-use technologies were developed

Table 8 summarizes the specifics of the findings that are known, based on the extant literature, about the six public/private partnerships discussed in this paper.

Recommendations regarding public/private partnerships

The Office of Technology Policy (1996) makes nine broad recommendations about public/private partnerships. These recommendations, like the findings of the Office stated above, are based in part from comments from extensive interviews with private sector participants, and in part on administrative experience. All do not follow from the extant evaluations discussed above, but all are likely politically important.

(1) Make partnership opportunities more accessible and easier to identify.
(2) Ensure effective protection of intellectual property.
(3) Make administration of partnership agreements more responsive to industry needs.
(4) Make partnership agreements easier to negotiate.
(5) Make partnership agreements more predictable.
(6) Help small businesses secure necessary financial advice from state programs and private sector sources.
(7) Further increase the private sector role in project definition and selection.
(8) Shift to commercial financial management practices.
(9) Continue developing systems to measure program results.

CONCLUSIONS

The findings and recommendations by the Office of Technology Policy, presented in the previous section, are what they are-findings and recommendations from a public sector agency based on private sector opinions.

It should be emphasized that these findings and recommendations are not part and parcel of an overall economic assessment of partnership arrangements, and certainly they are not an economic or political evaluation/critique of the United States' new paradigm for public/private technology partnerships. As well, these findings and recommendations do not reflect on the appropriateness of public involvement in terms of the economic rationale set forth in this paper. However, these findings and recommendations come after a reasonable period of time from the initiation of the new paradigm and thus should be given some credibility and perhaps even some generalizability for the experiences in other nations.

It is beyond the scope of this paper to comment on the rigor of the underlying opinion-based investigation that led to these findings or to assess the policy relevance of the recommendations. Both exercises could perhaps be useful as a foundation for generalizing about public/private partnerships.

Forms of public/private partnerships in the field of R&D and innovation have been identified in this paper in terms of an economic rationale for the existence of partnerships *per se,* in terms of a taxonomy of existing public/private partnerships, and in terms of a discussion of the legislative history and current activity of the major public/private partnerships in the United States.

Likewise, trends in the operation of these programs were noted both in terms of public resources so allocated and in terms of overall activity in such partnerships.

These trends underscore the importance of public/private partnerships as a tool to support industrial R&D. Especially noteworthy is that:

(1) public funds allocated to public/private partnerships as a percentage of total funded federal R&D have increased over recent years; they have increased from 3.6 percent in 1993 to 6.3 percent in 1996;
(2) direct support of R&D through public/private partnerships allocates more than twice as many federal dollars compared to indirect support of R&D through fiscal tax incentives.

However, given the material surveyed in this paper, it still remains to be the case that one cannot identify the extent to which one form of public/private partnership has been more or less efficient than another, where efficiency is defined in terms of the economic rationale for public/private partnerships set forth at the outset of this paper. Such an effort, while indeed important both to a domestic understanding of net social returns to public resources, is in most cases beyond the scope of possibility given the paucity of available data.

Such a conclusion raises the important question as to what type of evaluatory information would be needed. What is needed, and what is lacking in large part in the United States, includes systematic examinations of public/private partnerships patterned, perhaps, in the following manner. The first question that must be asked is:

> *Is there a clearly defined market failure motivating the establishment of the public/private partnership?*

The concept of market failure was also discussed. Market failure is the cornerstone upon which government claims a role as a participant in the innovation process. Accordingly, it must be the cornerstone upon which any evaluation is based. The answer to the above question is not easy to reach owing to the fact that institutional histories are often muddled over time, but more importantly the answer to the question requires an in-depth counterfactual analysis of how related markets would have worked in the absence of the existing partnership (Link and Scott 1998a, b). In an *ex post* fashion it is likely the case that each of the six public/private partnerships discussed herein could meet this test, but that conclusion is a personal opinion, although the existing and emerging case studies conducted by the Advanced Technology Program do seem to support this conclusion.

If it can be established that there is a market failure, then the next question is:

> *Is direct funding through a public/private partnership the appropriate policy response mechanism?*

The answer to this question requires one to "place" the program within a conceptual model like that illustrated in Figure 1. Certainly, there are alternative policy mechanisms to direct funding, and the pros and cons of each one have to be considered. It must be emphasized that market failure does not necessarily imply that direct funding is more appropriate than, say, indirect fiscal policies.

Finally, if it can be established that there is a market failure, and if it can be established that direct funding through a partnership format is appropriate, then a strategic plan must be institutionalized to collect over time reliable economic data for an evaluation of how well the partnership is overcoming the market failure as well as achieving its intended economic objectives (and of course at this point it would have been established that there is a mapping between the economic objectives of the partnership and the causes of the market failure). As was evident from Table 8, methodologies differ in terms of how this should be done, but the point to emphasize is that evaluation should be an ongoing process rather than an after the fact tool for justifying what has already occurred.

Thus, in conclusion, this paper, aside from its descriptive information, sets forth these important questions for consideration of how to think about and evaluate public/private partnerships in the United States and possibly in other industrialized nations.

REFERENCES

Advanced Research Projects Agency (ARPA) 1995: The Technology Reinvestment Project: Dual Use Innovations for a Strategic Defense. Washington, DC: Department of Defense.

Bator, Francis 1958: The anatomy of market failure, *Quarterly Journal of Economics,* 351-379.

Berger, Robert E., Little, Craig J. and Saavedra, Pedro J. 1992: Commercialization activities in the SBIR program, Part 1 and Part 2, *Journal of Technology Transfer,* Fall: 27-44.

Carr, Robert K. 1997: Federal Technology Expenses, mimeographed.

Chapman, Gary 1994: Congressional testimony, http://www.utt:xas.edu/lbj/2lcp/testimony/html.

Coburn, Christopher 1995: *Partnerships: a Compendium of State and Federal Technology Programs.* Columbus, OH: Battelle Press.

Council on Competitiveness 1996: Endless Frontier, Limited Resources: U.S. R&D Policy for Competitiveness. Washington, DC: Council on Competitiveness.

Economic Report of the President 1994: Washington, DC: Government Printing Office.

Erdilek, Asim 1989: Coalitions, cooperative research, and technology development in the globalization of the semiconductor industry, in Albert N. Link and Gregory Tassey (eds.), *Cooperative Research and Development: the Industry, University, Government Relationship.* Boston, MA: Kluwer Academic, pp. 187-208.

Institute of Defense Analysis 1994: The Economic Impacts of Technology Investments, final reports to DARPA.

Jaffe, Adam 1998: The importance of 'spillovers' in the policy mission of the Advanced Technology Program, *Journal of Technology Transfer,* 11-19.

Leyden, Dennis P. and Link, Albert N. 1999: Federal laboratories as research partners, *International Journal of Industrial Organization,* 17(4): 575-592.

Link, Albert N. 1996a: *Evaluating Public Sector Research and Development.* Westport, CT: Praeger.

Link, Albert N. 1996b: Research joint ventures: patterns from *Federal Register* filings, *Review of Industrial Organization,* October: 617-628.

Link, Albert N. 1998a: Case study of R&D efficiency in an ATP joint venture, *Journal of Technology Transfer,* 43-52.

Link, Albert N. 1998b: Public/Private Partnerships as a Tool to Support Industrial R&D: Experiences in the United States, final report to the OECD Working Group on Innovation and Technology.

Link, Albert N. 1998c: The US display consortium: analysis of a public/private partnership, *Industry and Innovation,* 5: 35-50.

Link, Albert N. and Bauer, Laura L. 1989: *Cooperative Research in U.S. Manufacturing: Assessing Policy Initiatives and Corporate Strategies.* Lexington, MA: Lexington Books.

Link, Albert N. and Scott, John T. 1998a: Assessing the infrastructural needs of a technology-based service sector: a new approach to technology policy planning, *STI Review,* 171-207.

Link, Albert N. and Scott, John T. 1998b: *Public Accountability: Evaluating Technology-Based Institutions.* Norwell, MA: Kluwer Academic.

Link, Albert N., Teece, David J. and Finan, William F. 1996: Estimating the benefits from collaboration: the case of SEMATECH, *Review of Industrial Organization,* October: 737-751.

National Academy of Sciences 1995: *Allocating Federal Funds for Science and Technology.* Washington, DC: National Academy Press.

National Institute of Standards and Technology (NISD 1995: Delivering Results: a Progress Report from the National Institute of Standards and Technology. Gaithersburg, MD: NIST.

National Science Board 1996: *Science & Engineering Indicators 1996.* Washington, DC: National Science Foundation.

Office of Management and Budget (0MB) 1996: Economic Analysis of Federal Regulations Under Executive Order 12866, mimeographed.

Office of the President 1990: *U.S. Technology Policy.* Washington, DC: Executive Office of the President, September 26.

Office of Technology Assessment (OTA) 1995: The Effectiveness of the Research and Experimentation Tax Credits. Washington, DC: Congress of the United States.

Office of Technology Policy 1996: Effective Partnering: a Report to Congress on Federal Technology Partnerships. Washington, DC: US Department of Commerce.

Organization for Economic Co-Operation and Development (OECD) 1998: *Technology Productivity and Job Creation: Toward Best Policy Practice.* Paris: OECD.

Ruegg, Rosalie T. 1998: The Advanced Technology Program, its evaluation plan, and progress in implementation, *Journal of Technology Transfer,* 5-9.

Tassey, Gregory 1995: Technology and Economic Growth: Implications for Federal Policy, NIST Planning Report 95-3. Gaithersburg, MD: National Institute of Standards and Technology.

Teece, David J. 1980: Economies of scope and the scope of the enterprise, *Journal of Economic Behavior and Organization,* 223-247.

United States General Accounting Office (GAO) 1994: Technology Transfers: Benefits of Cooperative R&D Agreements. Washington, DC: United States General Accounting Office.

United States General Accounting Office (GAO) 1996a: The Advanced Technology Program and Private-Sector Funding. Washington, DC: United States General Accounting Office.

United States General Accounting Office (GAO) 1996b: Federal R&D Laboratories. Washington, DC: United States General Accounting Office.