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U.S. SCIENCE POLICY: THE ERODING FEDERAL-UNIVERSITY CONTRACT

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by Vernon W. Ruttan[**]

For fifty years World War II and the Cold War provided the political and fiscal context for public investment in science and technology. In the U.S. the origins of today's R&D policies, rest primarily on the institutional arrangements established in the 1940's for the mobilization of science and technology in support of the war effort.

In 1940, Vannevar Bush, then president of the Carnegie Institution in Washington and a former dean of engineering at MIT, persuaded President Franklin Roosevelt (before the U.S. had entered World War II) that the university science and engineering communities should be mobilized in support of the development of the new military technologies that would be needed to defeat Germany and Japan. Roosevelt responded by establishing the National Defense Research Committee (later the Office of Scientific Research and Development). As the war was ending, Bush prepared at Roosevelt's request, a report, *Science: The Endless Frontier* (1945), that established the charter for postwar science policy (Dickson, 1988, p. 25; Bush, 1970, pp. 26-68). The Bush report insisted that basic research contributes not only to national security but also generates new processes, new products, new industries and new jobs.[1]

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[1] Bush was not the first to articulate what has come to be termed the linear or assembly line view of the relationship between advances in science and technology. Layton has pointed out that Joseph Henry,

For most of U.S. history, however, science policy had been derivative of technology policy. The primary instruments of technology policy were the discovery and development of natural resources, the support and development of internal improvements, the patent system, and military procurement (Dupree, 1957). The agricultural and industrial preeminence achieved by the U.S. in the late 19th and early 20th centuries was not a product of science based technology. The advances in technology associated with the exploitation of natural resources and advances in labor productivity were primarily the results of incremental advances in knowledge and technology associated with improvements in practice.

It was only after World War II that science and technology policy emerged as distinct fields of inquiry. The success of science in advancing military technology during the war created a presumption that advances in scientific knowledge could, in the postwar world, become a major source of economic growth and human welfare. The flow of vastly greater resources into support for scientific and technological research and training forced onto the agenda the question of how resources should be allocated among basic research, applied research and technology development, and commercialization and diffusion and within the several fields of science and technology.

THE UNDERINVESTMENT RATIONALE

It was not until the late 1950's and early 1960's, that a clear economic rationale for public support of scientific research began to emerge. In seminal articles published in the late 1950's and early 1960's Richard Nelson (1959) and Kenneth Arrow (1962) argued that the social returns to research investment exceeded the private returns realized by the individual firm.[2] Scientific and technical knowledge possess a

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the leading American scientist of the mid-19th Century, insisted that every mechanical invention was based on prior advances in theoretical science (Layton, 1997:206).

[2] The book, *The Rate and Direction of Inventive Activity*, based on a National Bureau of Economic Research conference held at the University of Minnesota in 1959 (Nelson, 1962), represented the landmark of early postwar thought on the economics of R&D. Most of the papers in the book still retain their currency.

"public goods" dimension. The benefits from advances in science and technology "spill over" to other firms and consumers. A clear conclusion was that the private sector could be expected to underinvest in scientific research and that public investment would be necessary to achieve a socially optimal level of research.

The market failure argument was initially applied to basic research. However, it was increasingly found to apply to applied research and technology development as well. The pathbreaking study by Griliches (1958) indicated exceedingly high rates of return to public investment in the development of hybrid corn. Studies of rates of return to publicly supported agricultural research, across a broad range of commodities and at the sector level, indicated social rates of return that were several multiples the average rate of return on conventional private sector investment (Evenson, Ruttan and Waggoner, 1979; Alston and Pardey, 1996:204-206). Studies by Mansfield (1977, pp. 144-66; 1986) of returns to research of private firms identified that in a wide range of industries social rates of return to investment in research was roughly double the private rate of return. The more productive private research programs typically have been those that have combined long-term sustained support by a firm with a sufficiently broad product line to be able to capture the benefits of a major in-house research program. In a later study Mansfield found an average annual rate of return on academic research, much of it publicly funded, of close to 30 percent (Mansfield, 1991).

These studies of the rates of return to research, combined with the more macroeconomic studies of the sources of productivity growth lead to a view that underinvestment in civilian R&D has represented a serious constraint on U.S. economic growth. The policy implication that was drawn from the evidence on under investment was the desirability of expanding public support to correct the underinvestment in research by the private sector.

By the early 1990s the underinvestment rationale for public sector support for the development of commercial technology was being supplemented by several new analytical developments (Feller, 1992). One line of argument suggests that the economies of scale realized by firms that are first to introduce a new technology, may result in a “lock in” of the initial technology even though subsequent technological developments might be more efficient. A second line of argument, based on strategic trade theory, is that in industry in which the optimum scale limits the number of low cost producers, wide bodied aircraft for example, subsidization of R&D may determine which firms can remain economically viable. Both the increasing returns argument and the strategic trade arguments suggest that government support may be necessary to stimulate the optimal level of private sector R&D. Critics argue, however, that the information necessary to fine tune subsidies to meet the implicit criteria of the two arguments is rarely available to government.

A third level of argument emphasizes the institutional constraints on the utilization and diffusion of knowledge. Much of the literature on the loss of international competitiveness on the part of U.S. industry emphasized that while the U.S. leads in making new scientific and technical discoveries and inventions, it has lagged behind foreign rivals in commercial development. The tacit knowledge associated with the development and utilization of new technology is difficult and expensive to transfer. In this view it is insufficient for government to support the generation of new knowledge and technology--greater weight should be given to the development of more effective institutional arrangements for the transfer of technology. This third argument is the basis for many of the new federal and state commercial technology development and transfer programs initiated in the 1970s and 1980s.

It is somewhat ironic that the underinvestment argument, which was initially developed as a rationale for public support of fundamental or basic research, has found its primary application in the evaluation of the returns to public and private research directed to commercial technology development. In the meanwhile, efforts by the scientific community to develop operational criteria for the allocation of resources to scientific research have foundered.

Contradictions in the Post War Dogma

The difficulty that the scientific community has experienced in confronting the issue of research resource allocation arises from a fundamental contradiction in the ideology (the dogma) of post World War

II science policy. This contradiction was expressed with particular force and conviction in the Bush report. As noted earlier the Bush report advanced an investment rationale for federal support of scientific research. The report coupled this investment rational with a profoundly agnostic view about its possible application in the allocation of research resources. The report insisted that “basic research is performed without thought of practical ends” (Bush, 1945:18). Furthermore, “Important and highly useful discoveries will result from some fraction of the undertakings in basic sciences but the results of any one investigation can not be predicted with accuracy” (Bush, 1945:19).

It is useful, in attempting to think about the criteria for the allocation of resources to basic research, and among fields of basic research, to remind ourselves of what it is reasonable to expect from basic research. Basic research can be viewed as an intermediate input that enhances the productivity of applied research and technology development. If applied research can be thought as a process of sampling from a distribution of potential processes or products, as in the Nelson-Winter evolutionary model, basic research can be though of as expanding the distribution of attributes within which the sampling occurs (Evenson and Kislev, 1975, pp. 140-155). By expanding the distribution basic research increases the probability of discovering technically and economically viable research outcomes and of reducing the cost of the search process.

This view leads to what might be termed a “double derived demand” model of the demand for basic research. The demand for technical change is derived primarily from the demand for commodities and services. The demand for advances in knowledge is in turn derived from the demand for technical and institutional change. But how can this model be employed in the development of criteria for research resource allocation if, in fact, the process of search and discovery in basic science--the supply of fundamental knowledge--is governed by a stochastic process?

Alvin Weinberg, then Director of Oak Ridge National Laboratory, attempted to respond to this question in addressing the future of “big science” in the early 1960s (Weinberg 1964). Weinberg first step was to insist on the legitimacy of both internal and external criteria in the allocation of research resources.

The two important internal criteria are: "(1) Is the field ready for exploitation? (2) Are the scientists in the field really competent?" These are the criteria theat typically carry the most weight in peer reviews of investigator initiated project proposals.

External criteria are generated outside of the scientific field. They attempt to answer the questions about why and how intensively a field of science should be pursued. Weinberg insisted that whether a field has scientific merit can not be answered within the field itself. "That field has the most scientific merit which contributes most heavily and illuminates most brightly its neighboring scientific disciplines" (Weinberg, 1964, p. 45). Writing from a mid-1960s perspective Weinberg argued, using this criteria, that molecular biology had greater scientific merit than high energy physics.

A similar argument has been made in a series of papers and articles by David, Mowery and Steinmueller (1992). They first reject attempts to apply conventional cost-benefit or rate of return analysis as a basis for resource allocation to or within basic research. Like Weinberg they regard basic research as an intermediate input that enhances the productivity of scientific effort in closely related fields and of applied research and technology development. But "the channels through which basic research yields economic payoffs are so complex, and the assumptions necessary to develop estimates of the returns on an investment in basic research are so fragile and unrealistic, that this exercise is of little use in guiding actual policy decisions" (David, Mowery and Steinmueller, 1992:87).[3]

David, Mowery and Steinmueller also emphasize that the "number and richness of links between the knowledge generated by basic scientific projects...are important determinants of the potential economic returns from discoveries in a specific discipline" (1992:84). These links may involve simple parametric

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[3] David, Mowery and Steinmueller note that basic research can also yield important externalities. (1) Basic research, when conducted in academic institutions, serves as a vehicle for the education and advanced training of scientists. (2) Basic research projects create social networks through which information that has not yet been reviewed and published diffuse rapidly. (3) Basic research projects induce advances in the technology of research, in both techniques and instrumentation, that reduce the cost and enhance the productivity of research effort. They also note that these characteristics are shared by applied research and technology development (David, Mowery and Steinmueller, 1992:75).

mapping of the results of one field into a closely related field--of the results obtained from model organisms (such as *E. coli*) to other organisms. Or they involve analogic links based on physical regularities across fields as in chemistry and physics. They also worry that the absence of such obvious linkages, may results in underinvestment in basic research, particularly if the costs of research are exceedingly high as in high-energy particle physics.

I am highly skeptical in the capacity of research agencies, particularly those that rely on peer review of investigator initiated projects, to select projects on the basis of the potential linkages or contributions to other fields of science. And I differ with David, Mowery and Steinmueller in that I find even gross estimates of rates of return useful as a first cut in determining whether investment in a field of basic science are paying off in terms of down stream productivity of applied research and technology development.

FROM SPIN-OFF TO SPIN-ON

In the U.S., it was only in the half century between the beginning of World War II and the end of the "Cold War" that the defense establishment came to dominate research and development (R&D) expenditures. For 50 years the Cold War provided the political and fiscal context for public investment in science and technology (Gibbons, 1995:119). During much of the period since World War II over half of the federal R&D budget was devoted to the advancement of defense technology. Much of the rest, including that devoted to space exploration, energy R&D, and even fundamental research in mathematics and the physical sciences, was supported because of its historical connection and potential relevance to national security (Cohen and Noll, 1996, p. 306). There has been a continuing argument about the impact of the very large role that military procurement and support has had on the vitality of civilian technology and on economic growth. Samuels has discussed these arguments in terms of spin-off, spin-away, and spin-on (Samuels, 1994:18).

The concept of spin-off rests on a view that military R&D represents a pervasive source of civilian technology. The requirements of technically sophisticated military systems contribute to the scientific and technical capacity of supplier firms. These firms in turn become a source of technologies which diffuse throughout the industrial system. Commonly cited products include insecticides, microwave ovens, satellites (for telecommunication, navigation, or weather forecasting), robotics, medical diagnostic equipment, lasers, digital displays, kevlar, fire resistant clothing, integrated circuits and nuclear power. Spin-off also involves process technology developed to meet the technically sophisticated performance requirements of military related technology.

The concept of spin-away refers to the progressive lack of articulation between technical change in the defense industries and the civilian economy. In a perceptive article published in the early 1960's Solo (1996) noted, that the rise in defense and space related R&D spending had not been accompanied by an increase in the rate of productivity growth. He argued that the technical distance between military and space research and civilian technology was widening and that communications between the two sectors was becoming more difficult. He argued further that military and space research, by drawing scientific and technological capacity away from civilian application may "actually deter the advance of industrial technologies and reduce the rate of economic growth" (Solo:52). And he urged that policies to enhance the transfer of knowledge and technology from military and space research to civilian application be more effectually institutionalized.

Spin-on refers to the transfer of off-the-shelf technologies from civilian to military applications. Historically spin-on of technology from civilian to military use has always been an important source of military technology. The most important innovations in microelectronics--Bell Laboratories' transistor, Texas Instruments' integrated circuits, Fairchilds' planar process and Intel's microprocessor--were all the product of research directed to civilian applications but which found immediate use in military applications. By the 1980's a perspective was beginning to emerge that the technological lead, relative to the civilian economy, previously enjoyed by military technology, was passing to the civilian economy. Not only is an increasing share of military procurement in the U.S. based on products initially developed for use in the civilian sector but an increasing share of these products are sourced internationally. "The Patriot missile deployed in the Gulf War of 1991 used technologically advanced components produced by Japanese subcontractors and developed initially for commercial markets" (Samuels, 1994:28).

There are three reasons for the shift toward spin-on. One is the higher performance that is increasingly required in civilian markets. Another is the large and increasing development costs for new technologies. Third is that the product life cycles in commercial markets are shorter than for military systems. As a result the technological sophistication of commercial products is increasingly running ahead of military requirements.

There can be little doubt that support for R&D and procurement from the military and space programs have had a significant impact on the focus of scientific effort and on direction of technical change. But whether it has been a net benefit or burden on the pace of technical change and productivity growth in the post-World War II period is problematic. Neither the logic nor the data are available to support an argument that in the U.S. technology is more advanced than it would have been if the same resources had been devoted directly to advancing civilian technology.

The pluralistic approach to S&T policy that has evolved in the U.S. means that there is no single science and technology priority setting agency. The process by which the budgets for R&D in the several departments and agencies are established is highly decentralized. The process involves the several executive departments and agencies, the authorization and appropriation committees of the House and the Senate, and at the level of the Executive Office of the President, the Office of Management and Budget (OMB), the Council of Economic Advisors (CEA) and the Office of Science and Technology Policy (OSTP). The flow of research resources from the federal government to its own research laboratories, to the private sector and to universities is exceedingly complex (Figure 1).

Stages in Research and Development Policy

In the half century since the end of World War II support by the federal government for R&D has experienced four major shifts (Figure 2). In the first two postwar decades support for R&D was initially based primarily on its potential for advancing the development of military technology and nuclear power. By the 1960's the objectives had been expanded to include the conquest of space. During this period federal support for research and development expanded rapidly.

This was followed by a decade, roughly corresponding to the Johnson and Nixon administrations, in which an effort was made to shift R&D resources to research areas deemed more relevant to social needs. President Lyndon Johnson called on the scientific community to redirect its efforts from basic research in the physical sciences to areas of science and technology more relevant to his war on poverty. President Richard M. Nixon urged the research community to focus on clean energy, control of natural disasters, transportation and drug control. Congress authorized a "war on cancer" that would demonstrate that the same focusing of scientific capacity that lead to mans landing on the moon could also result in a cure for cancer. During the Johnson and Nixon administrations federal, R&D expenditures declined and did not recover to their 1977 level until well into the Ford administration. Contributing to the decline was a vigorous policy criticism of the science community for its contribution to the technology employed in the Viet Nam War and of the contribution of the technology associated with industrial and agricultural intensification to the degradation of the environment.

During the Carter and Reagan administrations, public support for R&D was again refocused on the development of military technology. In the short period between 1980 and 1985 the military-related proportion of the federal R&D budget rose from 47 to 70 percent. A major secondary focus of federal R&D policy, in response to the slowing of productivity growth of the U.S. economy in the 1970's was an emphasis on improving the competitiveness of U.S. industry, particularly in those industries which produced high technology products or depended on high technology for process technology. Support for energy and environmentally related research was substantially curtailed. The Reagan administration was, except in the area of military technology, ideologically committed to reducing federal conduct and support of applied research and technology development in support of commercial objectives. However, it vigorously promoted other incentives, such as tax credits, for private sector R&D (Day and Ruttan, 1991).

The end of the Cold War has resulted in a slowing, during the Bush administration, and a decline, during the Clinton administration, of total federal support for R&D and of defense and space related R&D in particular. Commitment to an (almost) balanced budget, one of the few areas of broad agreement between President Clinton and his Republican opponents, placed the research community in competition with other discretionary (nonentitlement) components of the federal budget. Efforts by science bureaucrats to find something new to be afraid of in order to advance their budgetary agendas, such as global climate change, were unsuccessful in developing a sufficient political constituency to sustain the federal science and technology budget.

The Department of Defense and the Department of Energy, the agencies whose research budgets had benefited most from Cold War tensions, experienced substantial real dollar reductions in their R&D budgets during the 1990’s. By 1995 the Department of Defense's share of federal R&D expenditures had again declined to near one-half.

ISSUES IN SCIENCE AND TECHNOLOGY POLICY

An intense reexamination of science and technology policy has been underway in the U.S. since the late 1980s. Two factors have been particularly important in inducing this reexamination. One was the growing perception of the loss of U.S. leadership in a number of areas of commercial technology. A second was the winding down of the Cold War.

The post World War II relationship between the federal government, the scientific community, and the universities, where most basic research is conducted, has been governed by what some have termed an implicit social contract. “Government promises to fund the basic science that peer reviewers find most worthy of support, and scientists promise that the research will be performed well and honestly and will provide a steady stream of discoveries that can be translated into new products, medicines, or weapons" (Guston and Keniston, 1994:2).

The contract has been articulated in somewhat different terms by Representative George Brown (D-CA): "Science and the technology that it spawns are viewed as the cornerstone of our past, the strength of our present, and the hope of our future. An unofficial contract between the scientific community and society has arisen from these beliefs. This contract confers special privileges and freedoms on scientists, in the expectations that they will deliver great benefits to society as a whole" (Brown, 1992:781).

Brown has, over his long tenure in Congress, been one of the most ardent supporters of federal science. Yet he insisted that the contract needs to be redrawn. "The scientific community must seek to establish a new contract with policy makers, based not on demands for autonomy and ever increasing budgets, but on the implementation of an explicit research agenda rooted in [social] goals" (Brown, 1992:787).

The social contract has represented the central dogma of the appropriate relationship between the federal government and the scientific community and the research universities. But it has never been practiced in its idealized form. The agencies that administer federal research support, including the National Science Foundation, have always found it necessary to designate the program areas which would receive funding and the amount of funding for each area. Furthermore, federal funding of investigator initiated peer reviewed research has seldom accounted for as much as half of federal support for university research. Other support for university research has been through formula funding of agricultural research and institutional support for military, space and energy research. Much of the research conducted within government laboratories and of larger university programs have been evaluated by "merit review" methods such as periodic site visits.

Even in the 1960s and 1970s there was increasing concern in the Congress about the relevance of federally funded research. The 1970 Mansfield Amendment limited the ability of the Department of Defense to fund research unrelated to military application. In 1971 Congress earmarked funds for a

Research Applied to National Needs (RANN) program at the NSF. Several sources of tension between the federal government, the universities and the broader public community contributed to the erosion of the social contract between government and science.

One set of issues focused on public concern about the ethical implications of research (Woolf, 1994). Widely publicized cases of fabrication, falsification, and plagiarism created a perception of widespread scientific misconduct. Publicity about irresponsible conduct of research on human subjects and animals raised public concern about sensitivity of the scientific community to human values. Controversies about environmental and health hazards, particularly in the area of agricultural and biomedical research raised the level of distrust.

A second source of tension between universities and the Congress has been the rather arcane issue of indirect cost recovery for research. Research grants and contracts typically include overhead charges for services and facilities. These charges, which are intended to cover a share of overhead costs, for libraries for example, are typically aggregated into a "cost pool" to obtain an average overhead rate. In the late 1980s Representative John Dingle (D-MI) conducted hearings that focused on the inclusion of inappropriate items, such as a Stanford University luxury yacht, as a part of the overhead cost pool. Although the disputed items do not involve large amounts of money they have the capacity to generate dramatic headlines" -- "Tax Dollars Buy Stanford Booze" (Likins and Teich, 1994:187).

A third source of erosion has been the growing effort by universities to bypass the federal peer and merit review systems. During the 1990s there has been a dramatic increase in academic earmarking by the Congress. Universities have employed lobbyists to bring pressure on Congress to fund facilities construction and to provide institutional support for institutes and programs. Federal research agencies have been confronted by earmarked budget items which diverts funds from mission priorities. The effect of academic earmarking on the quality of research remains ambiguous (OTA, 1991:ch. 3). But it is clear that the pursuit of earmarked funding by universities has contributed to the erosion of the social contract.

There are a number of points that emerge rather clearly from this, from the previous discussion, and from earlier chapters in the book, *Technology, Growth and Development,* (Ruttan, forthcoming).

1) Public sector investment has played an important role in the emergence of every U.S. industry that is competitive on a global scale. This ranges from the role of the public sector in providing the highway infrastructure for the automobile, to the use of military procurement to supporting the development of the computer, to the support for the biomedical science that became the source of the biotechnology industries. It has also included support for education and research at U.S. universities.

2) The system of intellectual property rights that was originally developed to encourage the dissemination of technology is an essential component of the institutional infrastructure of any national science and technology policy. But it is not a sufficient instrument. There is a fundamental conflict with the use of the intellectual property rights system to reward the inventor (the equity argument that everyone should have the rights to the fruits of his/her own labor) and the social objective of inducing more rapid diffusion of technology.

3) During World War II and the initial years of the Cold War, massive investments in defense related science and technology, particularly military procurement, nuclear energy development and space exploration created a presumption that these investments could become a pervasive source of spin-off of commercial technology. As the Cold War came to a close and defense related research began to decline the weakness of this perspective became increasingly clear. We are in the process of returning to the more traditional spin-on relationship between miliary and commercial technology in which military technology becomes increasingly dependent on civilian technology.

4) We have now entered a period of increased skepticism, both in the public and private sectors, that investments in S&T lead directly to commercial technology development. One implication is that the postwar social contract between the scientific community and society, embodied in the linear or assembly line model of the relationship between science and technology, is rapidly eroding. This means that we are entering a period when investments in that part of basic science “performed without thought of practical

ends" (Bush, 1945:181) must be justified in terms of investment in advancing scientific culture rather than in terms contributions to other social and economic objectives. My own sense is that those areas of science and technology for which identifiable benefits are not anticipated within a quarter- to half-century time horizon will have increasing difficulty in achieving the credibility needed to lay claim to substantial scientific and technical resources. This implies very significant constraints on the ability to generate funding for big science. Big science investments will become increasingly dependent on trajectories opened up by little science. It also implies very serious constraints on basic or fundamental research, most of which is conducted in a university setting. It is quite possible that here will be some erosion in the one hundred or so universities that are presently classified as research universities.

There are several issues that I have not yet found a way to confront in this chapter. Among the most important is the question of the international division of responsibility for basic scientific research. Is, for example, the U.S. investing too much in scientific research? Those who argue the U.S. is investing more than an optimal level in scientific research (and in publicly supported technology development) make several points. Are we producing too many scientists? In almost all fields of science the distribution of output (measured by scientific publications) is highly skewed. Only slightly more than one third of all research papers ever published are cited as much as twice. It is argued that a reduction in the production of new scientists by one percent, or even ten percent, would not have a measurable effect on the advancement of scientific knowledge (Dresch, 1995). Is too much of the scientific knowledge produced in the U.S. spilling over into the rest of the world? One implication is that it seems increasingly clear that in the future international collaboration will be essential for congressional support of "big science" projects.

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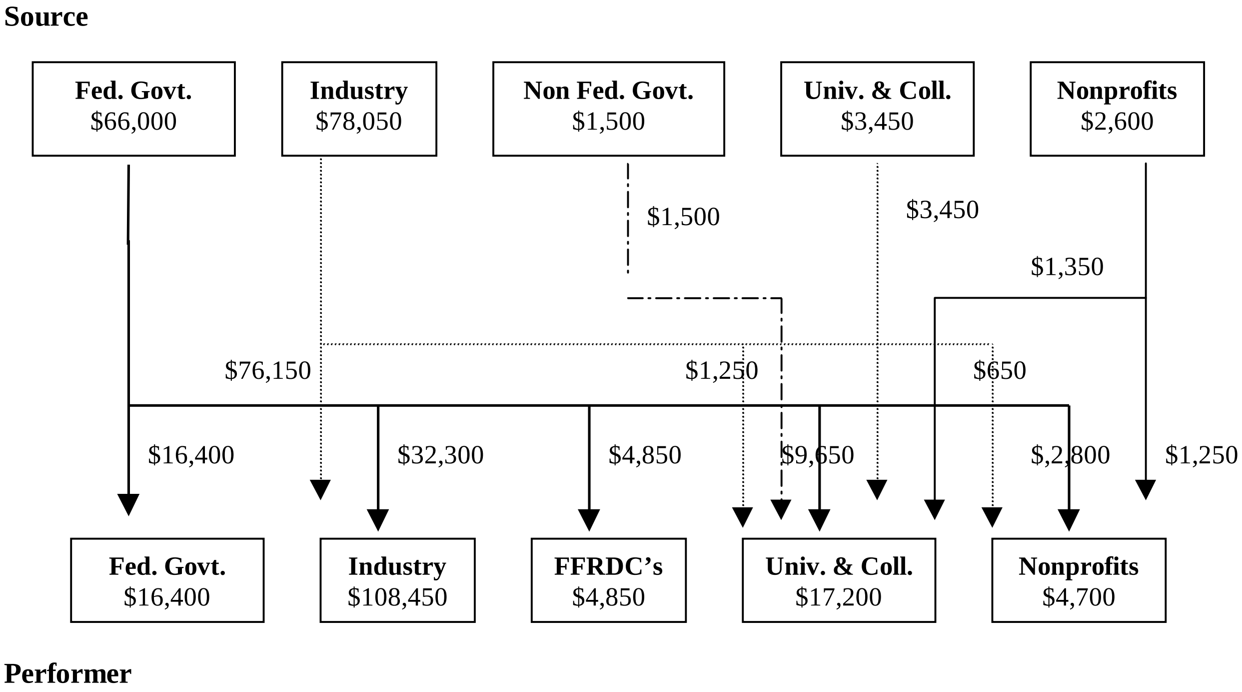
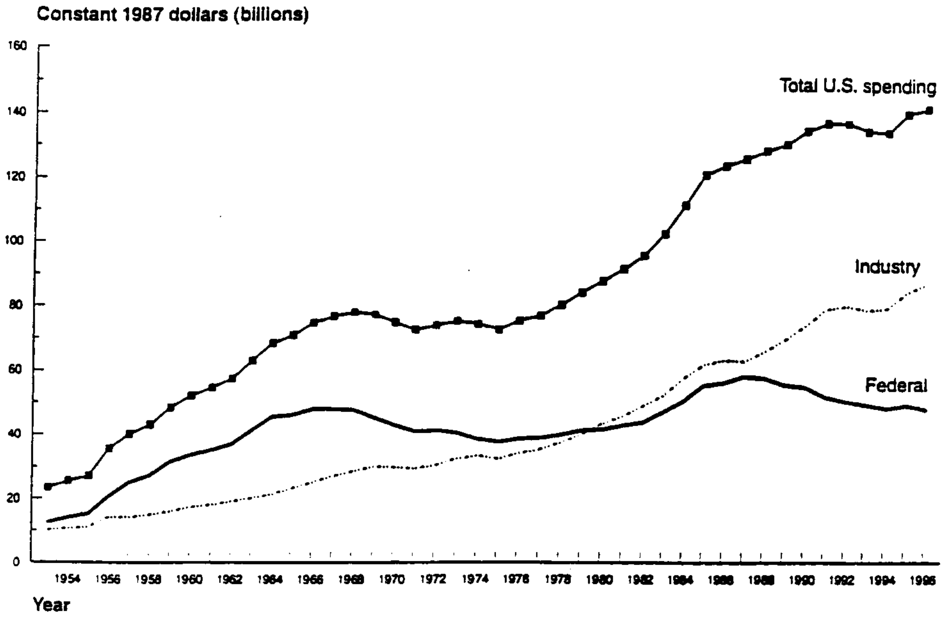
U.S. Research and Development Expenditures by Performing Sector and Source of Funds (1991)



Notes: FFRDC's refer to Federally Funded Research and Development Centers. Figures are in millions of current (1991) U.S. dollars.

Source: National Science Board, *Science and Engineering Indicators* (1991), Appendix Table 4-2, page 306.

Figure 2. U.S. R&D Spending, 1953-96



Source:	United States General Accounting Office. *Measuring Performance: Strengths and Weaknesses of Research Indicators.* Washington, DC: GAO/RCED-97-91, March 1997:30 (from National Science Foundation, Science Resources Studies Division).