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Science–The Endless Frontier: A Half Century Later

Murray L. Weidenbaum
Washington University in St Louis

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Murray Weidenbaum

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Contact: Robert Batterson
Communications Director
(314) 935-5676

Washington University Campus Box 1208 One Brookings Drive St. Louis, Missouri 63130-4899

Science — The Endless Frontier: A Half Century Later

by Murray Weidenbaum

Viewed from the perspective of half a century later, Vannevar Bush's landmark report, *Science — The Endless Frontier*,[1] was a pathbreaking effort which established the basic trend and orientation of federal science policy and activity for the following half century. Nevertheless, the Bush report also, and in some crucial ways, turned out to be irrelevant or counterproductive in terms of subsequent federal policy on research and development. These ambivalent conclusions arise from several key points which are developed in this paper.

The Fundamental Contributions of the Bush Report

It is difficult for most people to recall now the policy environment of 1945 for which Vannevar Bush's report was prepared. Although World War II was still raging, some farsighted folks began the important task of post-war planning. There was no science policy established for the federal government, nor had there been any special desire to do so. Of course, the advent of the atomic bomb dramatically convinced the public, as well as government officials, of the awesome power of science and technology. In less dramatic ways, scientists and engineers had made other vital contributions to the war effort, ranging from radar to code-breaking.

Nevertheless, in the entire prewar period, the history of federal support of science had been, in the main, incidental. Although significant government outlays were made for specific projects, no federal agency had been established to promote or support science or technology generally. Rather, the assistance that was provided was through a specialized agency devoted primarily to another function. The government's investment in technology thus was ancillary to the promotion of some other public purpose.

Murray Weidenbaum is the Mallinckrodt Distinguished University Professor at Washington University in St. Louis, where he is also chairman of the Center for the Study of American Business. He is indebted to Richard J. Mahoney, the Center's Distinguished Executive in Residence, for numerous helpful suggestions. This paper was prepared for an American Enterprise Institute conference on science policy, February 6, 1997.

The Department of Agriculture, for example, maintained an extensive research program designed to assist farmers in the production and marketing of their crops. The Department of Commerce contained the Coast and Geodetic Survey and a modest-size National Bureau of Standards, to provide the data on weights and measures needed by the commercial and industrial economy. The Department of the Interior supported the Geological Survey and the Navy Department operated the Naval Observatory. A small National Advisory Committee for Aeronautics was the forerunner of today's huge National Aeronautics and Space Administration. Even the Office of Scientific Research and Development, which Dr. Bush headed during World War II, was set up to develop and funnel scientific knowledge into the war effort.

Thus, the fundamental contribution of the report was something that we tend to take for granted these days — to convince key decisionmakers that the federal government should take on a major new responsibility for expanding scientific knowledge to benefit society in important ways, both military and civilian. In retrospect, it is conceivable that a different approach could have been taken. It could have been decided (by action or inaction) that it was up to the decentralized educational systems and business enterprises to determine the extent of the scientific activity that they would finance and conduct. The chances are that this alternate approach would have yielded a smaller overall commitment of resources to science and technology over the past 50 years, with the private sector taking on a major portion, but not all, of the public sector's funding role.

Two specific organizational changes to implement the new policy orientation also flowed from the Bush report — the establishment of the National Science Foundation (NSF) and the creation of a scientific advisory apparatus for the federal government. Bush envisioned ambitious roles for both the foundation and the advisory board, which he urged be attached to the foundation. The NSF was viewed as the proper place to house all of the federal government's basic research efforts, a proposal never fully adopted by the Congress. The advisory board concept has had a checkered career. Technically, the NSF — which is alive and well — has a prestigious board to provide counsel to the director of the agency.

However, it is at the White House level that scientific advisers influence national policy.

For many years until its demise, the President's Scientific Advisory Committee was a prestigious group that had important inputs on key defense and civilian issues. In more recent years, a full-time White House science adviser with a small staff has attempted to fill that gap.

Finally, words do have impact. The choice of the title of the Bush report, *Science — The Endless Frontier*, turns out to have been most fortuitous. It conveyed the vision of a continuing and ambitious effort.

The Gap Between Policy Recommendation and Policy Execution

As might be expected, a substantial gap has arisen between the policies recommended in the Bush report — even when the attempt was made to carry them out — and the actual execution of those policies.

In practice, the responsibility for promotion of science and technology is far more fragmented than envisioned by Vannevar Bush. The federal government has taken the lead position, given the magnitude of the resources that it can command and the scope of legislative and executive authority it possesses. Nevertheless, individual universities, research institutes, and companies exercise considerable discretion over the allocation of their own funds for science and new technology. In a society like ours characterized by a very substantial decentralization of decisionmaking, such competition may be especially beneficial. In any event, the Bush report has convinced us all that the promotion of science is an important and relatively high priority function worthy of considerable support in the public and the private sectors.

Similarly, the organizational responses to the specific proposals of the Bush report fall a bit short of Vannevar Bush's original vision, but the results may be described, perhaps somewhat generously, as a variation on his theme. The Bush report recommended the establishment of a National Research Foundation, an agency like the present NSF supervised by a high-powered Scientific Advisory Board, with broad authority over the nation's overall science policy. The NSF has become a significant source of financing academic research with an annual budget of about $2.1 billion. Contrary to Bush's expectations, however, several centers of significant scientific research operate outside the purview of the NSF. Neither the Office of Naval Research and the other military agencies nor the forerunners of the National Institutes of Health have turned over to the Foundation their extensive programs of basic research. In the fiscal year 1995, the NSF accounted for less than 16 percent of the federal government's total outlays for basic research of $13.5 billion.

Nevertheless, Vannevar Bush's general idea of a prestigious body to recommend areas of research emphasis continues to draw support. That is a key conclusion of the Committee on Criteria for Federal Support of Research and Development.[2] However, such a centrally located group would need to possess a demanding set of characteristics — competence, independence, and effectiveness. As my colleague Richard J. Mahoney has noted, the prospects for meeting these three criteria are "vanishingly small."

To turn an old phrase, the Congress giveth and the Congress taketh away (or vice versa). In rejecting his central proposal, the Congress gave Bush more than he wanted in terms of specifics. Contrary to his preferences, Congress authorized the NSF to support applied research and the social sciences, in addition to its primary focus on basic research in the natural sciences.

Today, neither the NSF nor its outside advisory board is an important player in the development or oversight of national, or even federal, science or research and development (R&D) policy. The key issues remain the province of the White House and/or the individual departments (Defense, Commerce, Energy, Health and Human Services, NASA, etc.). Specifically, the Bush report did not effectively respond to President Roosevelt's charge to recommend how to organize a program for continuing "the work . . . done in medicine." The Bush report envisioned a modest-size Division of Medical Research in the NSF, with a budget of $20 million in its fifth year of operation. The generously funded National Institutes of Health in the Department of Health and Human Services have more than filled that gap.

For a while (especially in the Eisenhower and Kennedy administrations), a presidentially appointed scientific advisory board operated independently from the NSF. That board did play a significant role in the review of important national issues (national security, etc.) with large scientific aspects. Subsequently, the role has been assigned to a single full-time scientific adviser with a modest-sized staff. The process of selecting the science adviser and the operation of that office often has encountered substantial criticism for their political nature. In any event, the status of that function seems to have been downgraded substantially in recent years.

Basic Shortcomings of the Bush Report

Acknowledging the important contributions of *Science — The Endless Frontier* should not prevent us from pointing out some of the shortcomings of that pioneering effort. Two of those limitations are especially worthy of our attention.

1) *The Bush report focused on basic science and university-trained scientific manpower, while ignoring or downplaying applied research and development.* In the following half century, by contrast, the emphasis in public policy has been on the entire category of R&D, which is a much broader concept. In terms of resources used, R&D is dominated by large engineering projects and other applied efforts. In the year 1994, for example, the United States devoted $100 billion to development and $72 billion to research (divided between $31 billion for basic research and $41 billion for applied research). At the federal level alone, $42 billion was devoted to development in fiscal year 1995 and $27 billion to research (almost equally divided between basic and applied).[3] (See Tables 1-3 for detailed data.) Conceptually, the interaction between research and development can occur in both directions. As Bush notes, scientific advances are the basic seeds of development. However, technological advances also provide apparatus to understand physical phenomena better. In practice, the ties between scientific work and technology have been close.[4]

It should be noted, however, that a distinguished committee of the National Academies of Science and Engineering and the Institute of Medicine has urged that attention of government policymakers should be focused on a narrower category that they call federal science and technology. That Committee on Criteria for Federal Support of Research and Development noted that only $35-40 billion a year of federal money is spent on advancing scientific knowledge and new technology. The remainder of federal R&D funds, in its view, is devoted to such activities as establishing production lines and developing operational systems for new aircraft, space vehicles, and weapon systems.[5]

As for the development of scientific and engineering manpower, which Bush saw as a key federal task, overwhelmingly that has been the task of the decentralized system of public and private colleges and universities. At the graduate level, much of the educational effort has been subsidized indirectly by the award of governmental R&D contracts to institutions and faculty. Direct federal financing of science education has been relatively modest and certainly not the pacing element. In any event, the direction of scientific and technical education in the United States has remained the responsibility of the individual school, college, and university. The key forces influencing that direction have been the peer group evaluations — formal and informal — within academia itself.

A major external force influencing enrollment in engineering degree programs has been the large fluctuations in the labor market for scientific and technological manpower. The strategic influence here has been waves of initiations (and terminations) of substantive government programs, notably large weapon systems, NASA projects, and nuclear development.

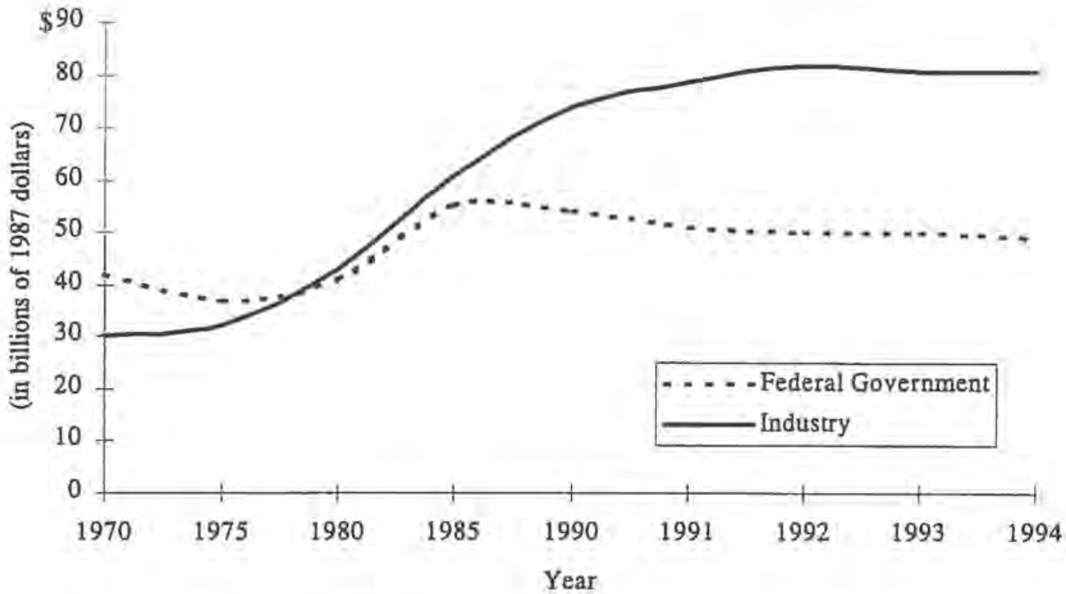
2) *The Bush report placed most of its attention on the role of the federal government and gave the private sector short shrift.* Apparently Vannevar Bush did not foresee the massive sums that the federal government would be supplying to industry in the form of R&D contracts, especially in the 1960s and 1970s — and a substantial $24 billion as recently as 1994.

Of far greater importance, the majority of R&D is now sponsored, financed, and performed by the private sector. In fact, R&D has been performed by business firms since the 1940s, so no significant change has occurred in this regard. In 1994, private industry performed $124 billion out of the entire $172 billion of R&D in the nation. An important shift has taken place in the last decade and a half in terms of determining the direction of R&D. Since 1981, business has replaced the federal government as the major source of financing and sponsorship of R&D. The private share has been rising steadily — from a minority 35 percent in 1960 to a dominant 64 percent in 1994 (see Figure 1).

The Bush report dismissed the role of the private sector with a very academically oriented statement, "The simplest and most effective way in which the Government can strengthen industrial research is to support basic research and to develop scientific talent." In the light of

Figure 1

Sponsorship of U.S. Research and Development



Source: U.S. National Science Foundation.

current experience, that is a very naïve and, if a professor may say so, a very academic viewpoint. The Bush model clearly assumes that basic research, presumably performed in university laboratories, is always the pacing element and that private industry stands around waiting to feed on the morsels thrown to it. Of course, Bush recognized in the body of his report that large industrial laboratories did exist.

While the relationships described in the Bush report surely continue, other models can be observed. On occasion, companies already well established in high-tech industries set up laboratories with wide-ranging agendas. The Bell Labs were the most distinguished examples of that phenomenon.

Moreover, the ability to commercialize the fruits of scientific research often has been deterred by a variety of governmental tax and regulatory policies, by and large a subject ignored by Vannevar Bush. At times the major barriers to the development of a large biotechnology industry in the United States have been the difficulties in obtaining the various approvals required from federal (and state) rulemaking agencies, rather than the limits in the availability of funding.

A 1996 survey of regulatory barriers to innovation in the United States revealed numerous other examples, including the following gems:

1. The extended nature of the Federal Aviation Administration certification process is a significant constraint on the introduction of new general aviation technology into commercial aircraft.

2. The Clean Air Act's rigid permit process locks companies into current manufacturing processes for five years, a serious impediment to new product development.

3. Differences in regulatory regimes among states are becoming greater than those among nations. An example is the new mandate in California that 2 percent of the vehicles sold in the state emit no pollutants.

4. The continued application of export controls on supercomputers, long after these controls were no longer viable, is a significant regulatory barrier. This barrier encouraged India to develop its own capabilities rather than purchase supercomputers from the United States.[6]

On other occasions, changes in the tax laws have raised or lowered the threshold for making a profitable investment in a new technology or in the new production process or product that results. Unfortunately, all this describes a very different world from 1945, a world that has developed since the Bush report was written. His recommendations in this regard (and they were a very minor part of the report), were to "remove present uncertainties" regarding the tax deductibility of R&D and to remove "certain abuses" in the patent system. On the latter point, Bush deferred entirely to the Commerce Department, which he expected would subsequently make specific suggestions.

In the tax area, by contrast, today there is widespread recognition of the need to reform the government's revenue structure to encourage the saving and investment needed to commercialize the new technology resulting from scientific advances.[7] Likewise, regulatory concerns are far broader than merely improving the patent system, helpful as that might be.

The limited policy responses to regulatory problems contained in the Bush report are at special variance with the current needs of high-tech industries. For example, when the members of the National Information Infrastructure (NII) were recently asked to identify the most important federal role in facilitating the NII (commonly referred to as the Information Superhighway), only 14 percent of these high-powered computer and component suppliers cited funding for R&D and 10 percent funding for applications and infrastructure development. In striking contrast, 43 percent said that repealing or reforming outmoded laws, rules, and regulations would be most helpful.[8]

When a similar question was asked about the role of state and local governments, comparable responses were received: only 12 percent identified funding for applications and infrastructure development, while 50 percent advocated repealing or reforming outmoded laws, rules, and regulations. Perhaps some of the limited interest in federal funding for R&D reflects the disenchantment over the increased politicization of the allocation process. The extended use of "earmarking" funds for specific projects in the districts of powerful members of Congress sends a very negative message about the lack of professionalism in the entire process.

On the positive side, government can play an important role in promoting science and technology — and with a minimum of expenditure or intervention in private decisionmaking. It is by creating an economic environment more conducive to the utilization of the fruits of research and development by eliminating or at least reducing the numerous obstacles to innovation that government itself has erected over the years. After all, it is futile for the federal government to pay vast sums into high-tech enterprises if, at the same time, it continues to erect statutory and administrative roadblocks to the application of those new technologies.

Because many federal agencies exempt existing facilities, products, and processes from their regulations (so-called grandfather clauses), the main burden of expanding regulation falls on new enterprises, new undertakings, and new technology. On the other hand, past experience with the U.S. government trying to force technological innovation is quite discouraging. The $3 billion the government wasted in the abortive effort to develop a commercial synthetic fuels industry is a striking case in point. An economic assessment of the efforts by Linda Cohen and Roger Noll is devastating:

> The entire synfuels program had a quality of madness to it. Project after project failed. . . . Goals were unattainable from the start. Official cost-benefit studies estimated net benefits in the minus billions of dollars.[9]

But synfuels was not an isolated example. Similar failures occurred in the aborted supersonic transport project and in the Clinch River breeder reactor. The financially hemorrhaging superconducting super collider was terminated more recently.[10]

The specific decisionmaking processes that government has used to make these allocations of federal resources to technology have varied over time. But the substantive characteristics seem rather durable. Government favors politically powerful firms, which usually means the older and more labor-intensive companies. Over the years, these firms have invested substantial resources in improving their presence in the government's decisionmaking processes in Washington. Moreover, they are the "squeaky wheels," suffering the most from competitive forces.

New and growing firms — especially in the high-tech area — may be economically strong, but they usually are politically weak. They have neither an extended record of financial contributions to political candidates nor sufficient knowledge of lobbying techniques nor large groups of agitated employees/voters. Moreover, they are too busy designing, producing, and marketing new products to devote much of their time, energy, and resources to politicizing.

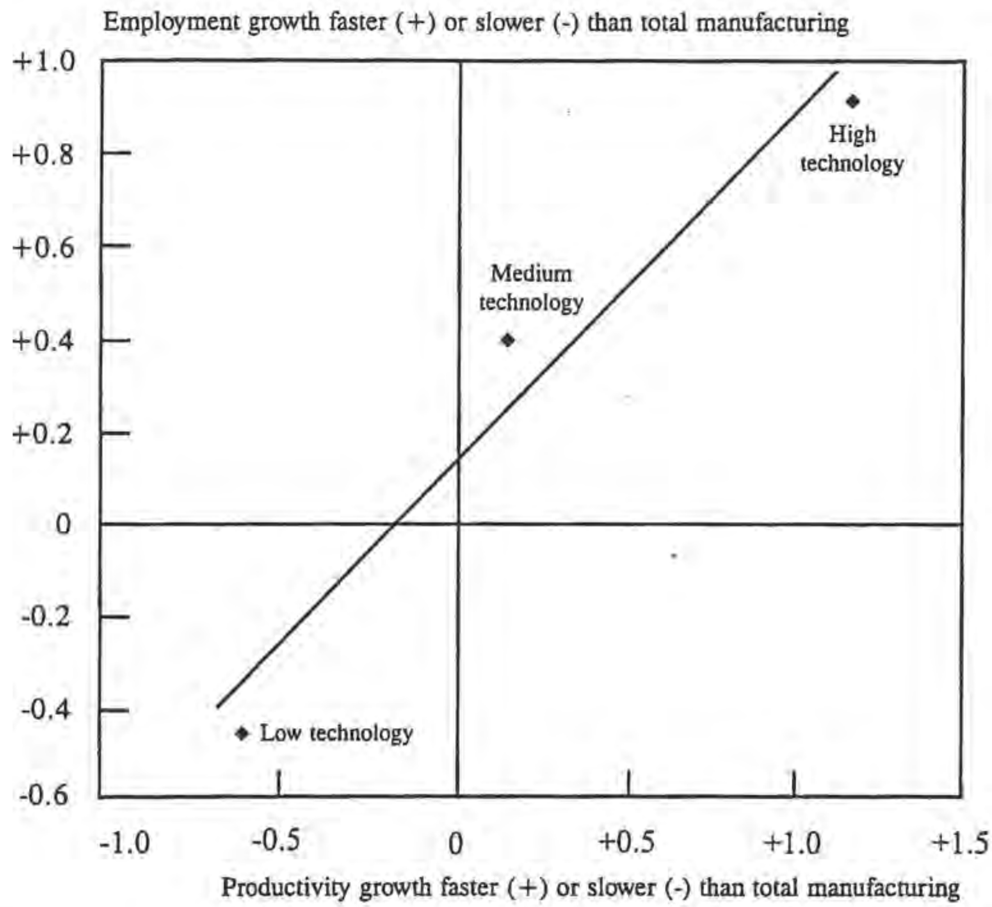
Conclusions

Despite its various specific shortcomings, Vannevar Bush's report must continue to get very high marks for its strategic value in developing widespread public and governmental interest in and support of promoting science — as well as new technology. In its fundamentals, the report surely has been a great success. The timing of the report, July 1945 — one month before the end of World War II — was lucky at the least.

Looking back over the past half century, the Bush report strongly influenced congressional action to establish the National Science Foundation specifically and to be generous in financing R&D generally. In light of the large federal government expenditures for scientific research, we tend to forget that — with the exception of agriculture — this phenomenon did not exist prior to World War II. The notion that the health of the economy as well as the strength of the national

Figure 2

G7 Productivity and Employment Growth in Manufacturing (High-, medium-, and low-technology industries, 1970-1993)



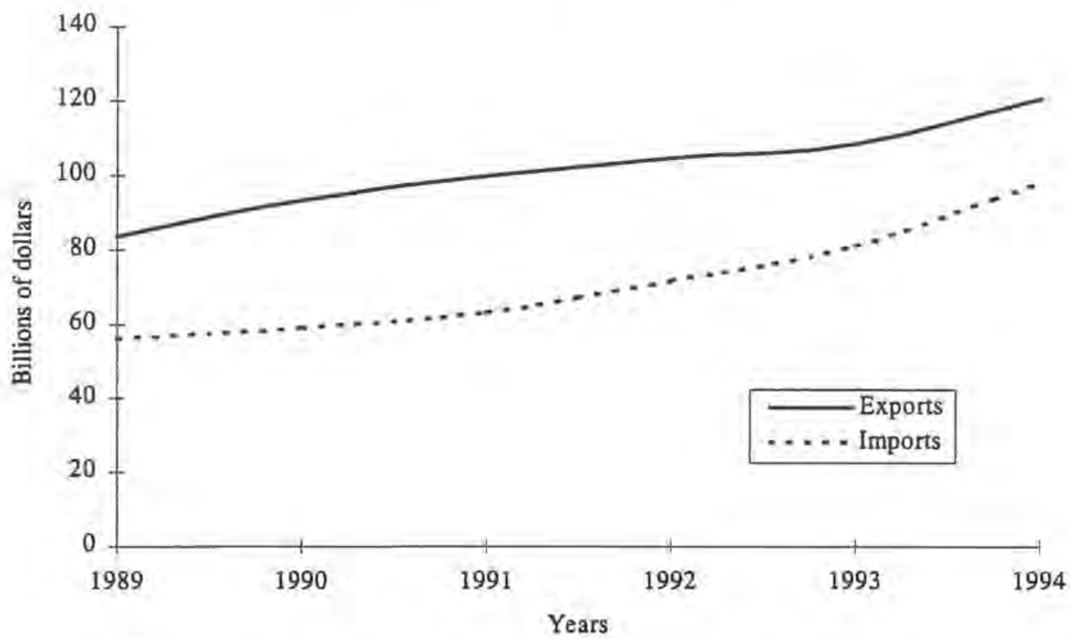
Source: Organization for Economic Cooperation and Development, *OECD Letter*, May 1996, p. 3.

security require new scientific knowledge has been validated repeatedly in the half century since Bush's report. Figure 2 shows the striking positive relationship between the level of technology used in an industry and its ability to create new jobs — and thus to contribute to economic progress.

In a less dramatic but perhaps equally strategic way, the high-tech industries have been the key growth areas of the American economy, generating a large share of the "good" jobs for the American work force. Our foreign trade in high-tech products — unlike the rest of the economy

Figure 3

U.S. Trade in Advanced Technology Products



Note: Includes the following subject categories: advanced materials, aerospace, biotechnology, electronics, flexible manufacturing, information and communications, life science, nuclear technology, optoelectronics, and weapons.

Source: U.S. Bureau of the Census.

— has produced trade surpluses year after year (see Figure 3).

Nevertheless, the role of government today in the promotion of science and technology is reminiscent of the incompetent motorist with one foot on the gas pedal and the other on the brake. Whether by design or default, government continues to place all sorts of tax and regulatory obstacles in the way of successful commercialization of the results of R&D. In doing so, it also — indirectly but powerfully — discourages potential private-sector sponsors and supporters of science and technology.

There are also new and compelling reasons to remedy the shortness of vision of science policy planners with reference to the private sector. Two key forces are reducing the federal role or at least the amount of money that the federal government is willing to spend for R&D — the end of the Cold War and the effort to eliminate the budget deficit. Yet, a third factor — the increasing competitiveness of the global marketplace — puts special pressure on American industry to emphasize new technology to enhance its productivity. As noted earlier, it is in the high-tech products and processes that the United States enjoys a substantial comparative advantage, and large surpluses of exports over imports.

The contrast between the public sector's attitude toward science and technology and that of the private sector is striking. Private industry faces an enlarged need for the fruits of R&D precisely at a time when the largest single source of federal funding in this area — and federal funding generally — is being squeezed.

Perhaps Dr. Bush was so caught up in the selfless patriotism that contributed so substantially to the successful prosecution of World War II that he ignored the often vital roles of politics and governmental bureaucracy in public policy decisionmaking. A fundamental rethinking of the place of science and technology in public policy seems in order. In the words of the Council on Competitiveness: "The U.S. R&D establishment has now entered a pivotal phase of transition . . ."[11] That transition is likely to be most successful if government takes on a more modest but still vital role — by shifting from being the prime financier and sponsor of R&D to that of creating the political and economic environment in which the private sector will be encouraged to take on that strategic task.

Even when giving full weight to its shortcomings and considering the ideas from the convenient vantage point of a half century later, we must readily acknowledge the positive contributions of Vannevar Bush's unique effort. Surely, for a product of less than eight months from start to finish, *Science — The Endless Frontier* set a standard for the effective completion of a successful government project that has rarely if ever been equaled.

Appendix

Table A1

Sources of R&D Funding in the United Sates
(in billions of constant 1987 dollars)

Year	Federal Government	Private Industry	Colleges, Universities	Other	Total
1970	42.6	29.7	1.3	1.0	74.6
1975	37.4	32.2	1.6	1.1	72.2
1980	41.4	43.1	1.9	1.3	87.7
1985	55.2	61.4	2.5	1.4	120.5
1987	57.9	62.6	3.2	1.6	125.3
1988	57.4	65.5	3.3	1.8	128.0
1989	55.3	69.2	3.6	2.0	130.1
1990	54.6	73.6	3.9	2.1	134.2
1991	51.4	78.7	4.1	2.2	136.4
1992	50.0	81.6	4.2	2.3	138.1
1993	49.8	81.1	4.2	2.3	137.4
1994	49.5	80.9	4.2	2.4	137.0

Source: U.S. National Science Foundation, *National Patterns of R&D Resources* (various issues).

Table A2

Performers of R&D in the United States
(in billions of constant 1987 dollars)

Year	Federal Government	Private Industry	Colleges, Universities	University Federal Centers	Other	Total
1970	11.8	51.3	6.8	2.1	2.6	74.6
1975	11.2	49.2	7.2	2.1	2.5	72.2
1980	10.8	62.1	8.6	3.2	3.0	87.7
1985	13.7	89.2	10.3	3.7	3.6	120.5
1987	13.4	92.1	12.2	4.2	3.4	125.3
1988	13.8	93.3	13.0	4.4	3.5	128.0
1989	14.0	94.1	13.8	4.4	3.8	130.1
1990	14.3	96.9	14.6	4.3	4.1	134.2
1991	13.0	99.4	15.1	4.4	4.5	136.4
1992	13.1	100.3	15.6	4.4	4.7	138.1
1993	13.4	98.7	16.2	4.3	4.8	137.4
1994	13.7	98.2	16.3	4.1	4.7	137.0

Source: U.S. National Science Foundation, *National Patterns of R&D Resources* (various issues).

Table A3

R&D in the United States, by Category
(percentage distribution)

Year	Basic Research	Applied Research	Development	Total
1980	14.1	18.5	67.4	100.0
1985	14.0	13.1	72.9	100.0
1989	14.9	23.9	61.2	100.0
1990	14.6	24.3	61.1	100.0
1991	17.0	25.6	57.4	100.0
1992	17.2	26.0	56.8	100.0
1993	17.4	26.9	55.7	100.0
1994	17.3	27.1	55.6	100.0

Source: U.S. National Science Foundation, *National Patterns of R&D Resources* (various issues).

Notes

1. Vannevar Bush, *Science — The Endless Frontier*, A Report to the President on a Program for Postwar Scientific Research, 1945 (reprinted by U.S. National Science Foundation, 1990).
2. Committee on Criteria for Federal Support of Research and Development, *Allocating Federal Funds for Science and Technology* (Washington, D.C.: National Academy Press, 1995), p. 4.
3. Data developed by the National Science Foundation. See *Statistical Abstract of the United States 1995* (Washington, D.C.: U.S. Government Printing Office, 1995), pp. 611-617.
4. Paula E. Stephan, "The Economics of Science," *Journal of Economic Literature*, September 1996, p. 1199.
5. Committee on Criteria for Federal Support of Research and Development, p. 4.
6. *Endless Frontier, Limited Resources: U.S. R & D Policy for Competitiveness* (Washington, D.C.: Council on Competitiveness, 1996), pp. 45, 64, 119.
7. See Michael Boskin, editor, *The Frontiers of Tax Reform* (Hoover Institution Press, 1996).
8. *The Unfinished Business of the NII* (Denver, Colo.: National Information Infrastructure Testbed, 1996), pp. 8-9.
9. Linda R. Cohen and Roger G. Noll, *The Technological Pork Barrel* (Washington, D.C.: Brookings Institution, 1991), p. 297.
10. Ibid., pp. 97-147, 179-215; Kent Jeffreys, *Super Boondoggle* (Washington, D.C.: Cato Institute, 1992).
11. *Endless Frontier, Limited Resources*, p. 3.