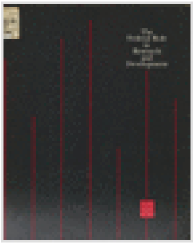

The Federal Role in Research and Development: Report of a Workshop (1986)

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The Federal Role in Research and Development

Report of a Workshop

by Kevin Finneran

for the
Committee on Science, Engineering,
and Public Policy

National Academy of Sciences
National Academy of Engineering
Institute of Medicine

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NOTICE

The workshop that is the subject of this report was held in November 1985 and was sponsored by the Committee on Science, Engineering, and Public Policy and the Academy Industry Program, both of which are activities of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

The National Academy of Sciences was established in 1863 by an Act of Congress as a private, nonprofit, self-governing membership corporation for the furtherance of science and technology for the general welfare. The terms of its charter require the National Academy of Sciences to advise the federal government, upon request, within the Academy's fields of competence. Under this corporate charter, the National Academy of Engineering and the Institute of Medicine were established in 1964 and 1970, respectively.

The Committee on Science, Engineering, and Public Policy addresses cross-disciplinary issues that affect the scientific and technological communities. The committee is charged with the responsibility "to deliberate on initiatives for new studies in the area of science and technology policy, taking especially into account the concerns and requests of the President's Science Advisor, the director of the National Science Foundation, the chairman of the National Science Board, and the chairmen of key science and technology-related committees of the Congress."

The Academy Industry Program was established in 1983 as a mechanism for bringing the intellectual and financial resources of United States industry to the work of the National Research Council (the working arm of the National Academies of Sciences and Engineering that carries out many of the studies done in the Academies' names) and for ensuring the strength of institutional ties to the industrial, scientific, and technological communities. Participating companies, numbering over 60, contribute a total of $1 million each year to support studies, seminars, symposia, and other programs on problems of national consequence for which science and technology are central. The program also provides opportunities for corporate leaders to discuss national issues with policymakers from the federal government, universities, and other sectors.

The workshop was supported by the Academy Industry Program and the Office of Energy Research, U.S. Department of Energy.

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Summary

This report summarizes two days of intensive discussions on two overlapping topics: (1) capabilities for measuring economic returns on federal investments in research and development (R&D), and (2) principles for federal support of applied research. Predictably, while both topics were illuminated and the questions about them sharpened, in neither case did firm answers appear.

Measuring Economic Returns

There is abundant anecdotal evidence indicating the benefits of federal investments in research and development; for example, work in high energy physics has stimulated advances in ultrahigh vacuum technology, superconducting magnets, and minicomputers. But difficulties arise in moving from qualitative to quantitative judgments. The use of economic measures to evaluate federal R&D is, at best, problematical. Most governmental funding for research and development goes to projects that produce results with no agreed economic values, forcing the use of spillover effects as a measure of value. If we look to the gross national product as an indicator of increased productivity from federal research and development, we find that the government's contribution is measured by its cost, not by its value, so that we cannot determine productivity. The weaknesses of the data base undermine the usefulness of quantitative results. A major problem is the lack of disaggregated data on the federal budget for research and development.

Further, economic analyses may not incorporate real benefits. They tend to focus on innovation and gains in productivity, overlooking the gains accruing from maintaining the scientific enterprise, including research training.

However, while cognizant of the limits on studies that have been done on economic returns of federal investments in research and development, we also can see their value. We may not have a definitive measure of the rate of return, but we now understand that such investments affect productivity indirectly through their influence on private R&D and we realize that federal procurement may be an even more powerful stimulant to private R&D. We also have a better understanding of what constitutes R&D inputs as well as an appreciation of the fact that more disaggregated studies are necessary in order to obtain reliable information about the impact of federal investments upon research and development.

Overall, it was concluded that:

- Economic returns are not the explicit purpose of most federal investments in research and development—biomedical research is an example. Therefore, estimating rates of return may be misleading, attracting attention to simple economic measures at the expense of more important, but less quantifiable, criteria for federal R&D.
- Existing economic models have serious shortcomings that limit their use.
- Even if perfected, economic models should be regarded as merely some among many criteria for guiding federal R&D policy.

Principles for Federal Support of Applied Research

Whatever the political party in power, the government has endeavored to fund applied or targeted research on its merits or because of specific political conditions, rather than in accordance with broadly accepted criteria. Thus, targeted research in agriculture, health, defense, and aeronautics has had a long history of support and of practical success. In contrast, some efforts, such as those in the 1970's on energy, have attracted rancorous debate, and ambitious programs for targeted research championed by the Kennedy, Nixon, and Carter Administrations failed to survive the political process.

This checkerboard history suggests some guidelines for framing applied research initiatives to make them more palatable politically and more effective technically:

- Define goals modestly.
- Tailor the program to fit the structure of the target industry.
- Match the needs of users and the capabilities of research institutions.
- Emphasize generic research, leaving product design and commercialization to the private sector.

Further, the analysis of federal policies in relation to applied or targeted research discloses several realities:

- Research cannot be divided easily into separate stages.
- The crucial criterion for research with commercial applications is not its ideological correctness but its aptness for the specific industry or industries it aims to serve.
- The success of research in stimulating innovation depends on the full range of policies affecting the target industry.
- Targeted research initiatives must walk a political tightrope, balancing the promise of near-term payoffs with technical realities, ambition with the risk of failure, and dispersed benefits with project control.

Preface

Program managers in the Department of Energy's (DOE's) Office of Energy Research, like their counterparts in other federal research departments, are seeking constantly to evaluate the impact of their efforts and to explain to policymakers the value of federal research. Recognizing that increased industrial productivity stimulated by advances in science and technology is one of the primary benefits of federal research and development, the DOE managers asked the Committee on Science, Engineering, and Public Policy (COSEPUP) of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine to examine existing methods for measuring economic returns to federal spending on R&D.

That request coincided with a desire among COSEPUP members to review the history of federal policy toward applied or targeted research and development to identify the underlying principles guiding government funding of research with near-term commercial applications. Because of the overlap between the two topics, COSEPUP combined them into a workshop on "The Federal Role in Research and Development." Four members of COSEPUP—Norman Abramson, Emilio Daddario, Gerald Dinneen, and Zvi Griliches—joined me on a subcommittee to organize the workshop.

It was apparent from the beginning that a two-day workshop would not provide definitive answers to these complex questions. Instead, the workshop would be an opportunity to explore the issues and to determine if there was fruitful ground for a more comprehensive study by COSEPUP. Fourteen papers on the history, politics, and economics of federal R&D were commissioned, and about 80 leaders from government, industry, and academia were invited to discuss the papers at the workshop, held at the National Academy of Sciences in Washington, D.C., on November 21-22, 1985. Titles and authors for those commissioned papers are appended to this report, as is a list of workshop participants.

Measuring Returns on Federal Investments

Introduction

The popular conception of why science and technology are important to the nation has shifted several times since the end of World War II, when the government began to play a major role in R&D funding. At various times, scientific discovery and technical innovation have been hailed as the key to improving military security, advancing national prestige, solving medical and social problems, and, most recently, enhancing economic competitiveness. These shifts in attitude are reflected in changes in federal R&D funding: the waxing and waning of defense R&D; the creation of the National Aeronautics and Space Administration and generous funding of the Apollo Project and the space station; growing budgets for health, transportation, and environmental research; and the massive effort to develop alternative energy sources.

In his opening remarks, Frank Press observed that another fundamental shift is under way:

> We always knew that science, technology, and national well-being were bound together; now that realization has arrived politically; it has arrived economically. It is that realization that is driving a bewildering set of new relationships, new centers and institutes, new relations between industry and universities, even new ways of doing research, and new ways to increase productivity and competitiveness using new technologies.

In spite of the significant shifts in emphasis and priorities, overall federal R&D funding has grown annually since 1950, except for the period 1967–1975. Further, the shifts in popular rationale for federal R&D funding did not add much new to the debate. Vannevar Bush's *Science, the Endless Frontier,*[1] published in 1945 and regarded widely as the seminal argument for federal support for science and technology, includes most of the subsequent justifications for federal R&D funding.

Bush called for a government commitment to scientific and technical research because it would improve public health, help defend the nation, fuel economic growth, and provide jobs in new industries. Though a fervent advocate of basic research, Bush recognized that new knowledge is not the end product of research, that scientific discoveries are linked to technical breakthroughs that could result in new products and processes, stimulating economic activity and improving the quality of life. While Bush succeeded in making his overall case for federal R&D spending, not all of his assertions carried political weight. Military R&D had been the shining success of World War II, and the federal R&D commitment was based primarily on the need to maintain national security. Federal funds for biomedical R&D did not grow significantly until the late 1950's, and R&D aimed at improving industrial productivity came even later. Of course, Bush and others were making the multipurpose case for federal R&D throughout the period, but such events as the launch of Sputnik and the energy crisis determined which ideas would enter the popular debate.

Alvin Trivelpiece asked the workshop participants to take two approaches to improving the argument for stable federal R&D funding: to explain more clearly to the public the federal role in scientific and technological advances that improve the quality of life and to provide Congress with a simple measure of the benefits of federally funded R&D. Representative Doug Walgren explained that Congress does not have a systematic method for making research policy decisions and that the benefits of federal R&D are often slow to mature and hard to identify. He encouraged members of the scientific community to present their points of view to Congress personally in whatever ways they think will be effective.

A review of federal R&D funding since World War II illustrates how political events have shaped both funding levels and the rationale for the funding. As President Reagan's Science Advisor George Keyworth said at the workshop:

> I think it's important to remember that as much as we scientists may believe in science for science's sake, as much as we're willing to argue for the aesthetic or intangible benefits we derive from intellectual activity, government invests in science in order to stimulate a return to the taxpayers whose money is collected for that purpose.

While acknowledging that finding an accurate measure of economic returns to federal R&D probably would not be possible, Frank Press endorsed the continued effort to identify economic and other benefits of federal R&D:

> Although it is not easy to do so, it is appropriate to try to make an economic valuation of federal R&D. We should never stop arguing the intellectual case for science; neither should we shrink from explaining the contribution of new science and technology knowledge to productivity, to the growth of the GNP, to the health of our citizens, and to our ability to feed them well and cheaply.

The following sections describe the history of federal R&D funding, the acknowledged benefits of federal investments, the economic methodologies used to measure the benefits, and the usefulness of the results of R&D measurement studies.

History of Federal R&D Funding

The first consistent federal research funding began with the Hatch Act (1887), which provided support for agricultural experiment stations connected to the land-grant colleges.[2] While many land-grant colleges founded engineering experiment stations in the first four decades of the 20th century, none of those stations received federal funds. Agricultural science enjoyed its premier status for federal research funding until the Second World War. The 1940 federal R&D budget of $74.1 million ($590 million in 1985 dollars) was divided among the Departments of Agriculture ($29.1 million), Defense ($26.4 million), Interior ($7.9 million), and Commerce ($3.3 million); the Public Health Service ($2.8 million); and the National Advisory Committee on Aeronautics ($2.2 million). All federal funding was limited to projects related directly to the missions of federal agencies. The federal government funded between 12 and 20 percent of all U.S. R&D in the 1930's. Industry contributed about two thirds of the total, and universities, state governments, private foundations, and research institutes, the rest.[3]

World War II changed everything. Annual spending for the Manhattan Project alone was greater than the total of all federal R&D funding prior to the War. The Department of Defense (DOD) budget, which did not include the Manhattan Project, grew from $26.4 million in 1940 to $513 million in 1945 (from $210 million to $3.1 billion in 1985 dollars). During the same period, the total federal R&D budget grew from $74.1 million to $1.6 billion (from $590 million to $9.8 billion in 1985 dollars). Most significant for the future of federal involvement in R&D was the creation of the Office of Scientific Research and Development (OSRD), a nonmilitary agency that funded war-related research in the private sector. The OSRD facilitated increased participation by scientists in the selection of military research projects and even in the provision of direct advice to the President. The enhanced role of industry and university scientists in federally funded projects set the stage for the revolution in federal R&D funding following the War.

Postwar Spending Federal R&D funding fell off sharply after the War, from $1.6 billion in 1945 to a low of $855 million in 1948 (from $9.4 to $3.4 billion in 1985 dollars), but this was still six times the 1940 level in constant dollars, and the phasing out of the Manhattan Project accounted for virtually all of the reduction. Federal R&D spending grew annually in constant dollars from 1953 to 1966, declined each year from 1967 to 1975, and has increased steadily since, recovering to its 1966 level by 1983 (see Table 1). Private R&D grew steadily but more slowly than federal expenditures until the mid-1960's. Since then, private R&D has grown at a faster rate and has exceeded federal spending since 1978. Political events explain the uneven growth of the federal R&D budget. The Korean war and the growing military sophistication of the Soviet Union spurred rapid growth in the defense budget, from $823 million in 1951 to $6.6 billion in 1961 (from $3.3 billion to $22.3 billion in 1985 dollars). The launching of Sputnik in 1957 led

Table 1 R&D in Constant 1972 Dollars, 1953–1984
(In millions)

Year	Total	Federal	Private	% Federal
1953	$ 8,702	$ 4,675	$ 4,027	53.7
1954	9,456	5,247	4,209	55.7
1955	10,121	5,473	4,648	54.1
1956	13,296	7,714	5,582	58.0
1957	15,034	9,397	5,637	62.5
1958	16,214	10,262	5,952	63.3
1959	18,303	11,917	6,386	65.1
1960	19,693	12,725	6,968	64.6
1961	20,664	13,351	7,313	64.6
1962	21,820	14,048	7,772	64.4
1963	23,829	15,651	8,178	65.7
1964	25,930	17,241	8,689	66.5
1965	26,896	17,443	9,453	64.8
1966	28,442	18,180	10,262	63.9
1967	29,241	18,176	11,065	62.2
1968	29,833	18,108	11,725	60.7
1969	29,586	17,209	12,377	58.2
1970	28,613	16,316	12,297	57.0
1971	27,814	15,615	12,199	56.1
1972	28,477	15,808	12,669	55.5
1973	29,147	15,594	13,553	53.5
1974	28,736	14,826	13,910	51.6
1975	28,153	14,537	13,616	51.6
1976	29,510	15,072	14,438	51.1
1977	30,506	15,382	15,124	50.4
1978	32,002	15,878	16,124	49.6
1979	33,612	16,407	17,205	48.8
1980	35,133	16,541	18,592	47.1
1981	36,859	17,124	19,735	46.5
1982	38,742	17,841	20,901	46.1
1983 (est.)	40,568	18,622	21,946	45.9
1984 (est.)	42,951	19,577	23,374	45.6

Source: The figures for 1953–1964 are from *National Patterns of Science and Technology Resources, 1953–77,* and the later figures are from *National Patterns of Science and Technology Resources, 1984.* Washington, DC: National Science Foundation.

to the transformation of the National Advisory Committee for Aeronautics (NACA) into the National Aeronautics and Space Administration (NASA) with a budget that grew from $89 million in 1958 to $5.9 billion in 1966 (from $300 million to $17.8 billion in 1985 dollars), accounting for 19 percent of all U.S. R&D in 1966 (see Table 2). The late 1960's saw an increased effort by government to use science and technology to solve social problems. While the overall R&D budget fell in the late 1960's, R&D budgets grew for the Department of Transportation, the Department of Health and Human Services (then Health, Education, and Welfare), and the Office of Economic Opportunity. The major political event of the 1970's was the energy crisis, and federal energy R&D grew from $556 million in 1971 to $3.6 billion in 1980 (from $1.35 billion to $4.3 billion in 1985 dollars—see Table 3). Research and development in the Environmental Protection Agency, spurred by the political influence of the environmental movement, also grew quickly in the 1970's.

Defense R&D always has dominated the federal budget, never accounting

Table 2 Distribution of Federal R&D in Defense, Space, and Other Programs
(Percents)

Year	Federal				Non-Federal
	Total	Defense related	Space related	Civilian related	
1953	54	48	1	5	46
1960	65	52	3	9	35
1961	65	50	6	9	35
1962	64	48	7	9	36
1963	66	41	14	11	34
1964	66	37	19	9	34
1965	65	33	21	11	35
1966	64	33	19	12	36
1967	62	35	14	13	38
1968	61	35	13	13	39
1969	58	34	11	13	42
1970	57	33	10	14	43
1971	56	32	9	15	44
1972	56	32	9	15	44
1973	53	30	8	15	47
1974	51	27	8	16	49
1975	51	26	8	17	49
1976	51	26	8	17	49
1977	50	25	8	17	50
1978	50	24	7	19	50
1979	49	23	7	19	51
1980	47	22	7	18	53
1981	46	23	7	16	54
1982	46	25	7	14	54
1983 (est.)	46	27	6	13	54
1984 (est.)	46	29	6	11	54

Note: Detail may not add to 100 because of rounding.

Source: *National Patterns of Science and Technology Resources, 1984*. NSF 84-311. Washington, DC: National Science Foundation, 1984.

for less than 49 percent of total federal R&D funds (see Table 4). And, if one includes federal expenditures for space and atomic energy, which are closely linked to defense, military R&D dominates the federal R&D budget totally, particularly for funds going to industrial researchers. In 1982, DOD, DOE, and NASA accounted for 97 percent of all federal R&D funds going to industrial firms. The emphasis on military R&D meant that federal R&D funding was concentrated on development projects in a few industries. In 1981, more than half of all federal R&D was devoted to aircraft and missiles, and almost one quarter to electronics. More than 85 percent of all defense R&D was development research, 11 percent was applied research, and 3.2 percent was basic research. By comparison, nondefense spending in 1982 was divided almost equally among basic research, applied research, and development.[4]

Research Performers Federal funding also has had an effect on where research is done. Before World War II, most R&D was performed in industry, and this is still

Table 3 Federal Funds[1] for R&D, by Budget Function: 1971–1986

Function	1971	1972	1973	1974	1975	1976	1977
	Million dollars						
Total	$15,542.5	$16,495.9	$16,800.2	$17,410.1	$19,038.8	$20,779.7	$23,450.0
National defense	8,109.9	8,901.6	9,001.9	9,015.8	9,679.3	10,429.7	11,863.8
Health	1,287.8	1,546.7	1,585.0	2,068.6	2,170.2	23,502.6	2,628.5
Space research & technology	3,048.0	2,931.8	2,823.9	2,701.8	2,764.0	3,129.9	2,832.5
Energy	555.8	574.0	629.7	759.2	1,363.4	1,648.5	2,561.8
General science	512.5	625.3	657.6	749.4	813.3	857.7	973.8
Transportation	727.9	558.2	571.5	693.4	634.9	630.5	708.4
Natural resources & environment	415.5	478.5	553.8	516.0	624.3	683.0	753.1
Agriculture	259.0	294.4	308.1	313.1	341.8	382.5	456.7
Education, training, employment & social services	215.4	235.3	290.4	236.4	238.6	254.8	230.1
International affairs	31.9	28.6	28.3	23.8	29.0	42.4	66.3
Veterans benefits & services	62.9	69.1	74.3	84.8	94.8	97.7	107.0
Commerce & housing credit	89.5	49.7	50.2	50.8	64.9	68.7	70.5
Income security	144.9	106.3	106.3	70.9	71.9	48.3	55.2
Administration of justice	10.4	23.4	33.2	34.7	44.3	48.3	29.9
Community & regional development	64.6	65.8	78.4	82.1	92.5	108.5	100.9
General government	6.6	7.6	7.4	9.3	11.7	11.9	12.6
	Million constant 1972 dollars[2]						
Total	$16,254.4	$16,495.9	$16,084.4	$15,536.4	$15,446.0	$15,756.5	$16,659.6
National defense	8,481.4	8,901.6	8,618.4	8,045.5	7,852.8	7,908.5	8,428.4
Health	1,346.8	1,546.7	1,517.5	1,846.0	1,760.7	17,821.2	1,867.4
Space research & technology	3,187.6	2,931.8	2,703.6	2,411.0	2,242.4	2,373.3	2,011.7
Energy	581.3	574.0	602.9	677.5	1,106.1	1,250.0	1,820.0
General science	536.0	625.3	629.6	668.7	659.8	650.4	691.8
Transportation	761.2	558.2	547.2	618.8	515.1	478.1	503.3
Natural resources & environment	434.5	478.5	530.2	460.5	506.5	517.9	535.0
Agriculture	270.9	294.4	295.0	279.4	277.3	290.0	324.5
Education, training, employment & social services	225.3	235.3	278.0	211.0	193.6	193.2	163.5
International affairs	33.4	28.6	27.1	21.2	23.5	32.2	47.1
Veterans benefits & services	65.8	69.1	71.1	75.7	76.9	74.1	76.0
Commerce & housing credit	93.6	49.7	48.1	45.3	52.7	52.1	50.1
Income security	151.5	106.3	101.8	63.3	58.3	36.6	39.2
Administration of justice	10.9	23.4	31.8	31.0	35.9	36.6	21.2
Community & regional development	67.6	65.8	75.1	73.3	75.0	82.3	71.7
General government	6.9	7.6	7.1	8.3	9.5	9.0	9.0

[1] Listed in descending order of 1986 budget authority. Data for the period 1971–77 are shown in obligations; data for 1978–84 are shown in budget authority.

[2] GNP implicit price deflators used to convert current dollars to constant 1972 dollar.

Note: Detail may not add to totals because of rounding.

Source: *Federal R&D Funding by Budget Function, Fiscal Years 1984–86.* NSF 85-319. Washington, DC: National Science Foundation, 1985, and earlier years.

true today. Industry performed 73 percent of all U.S. R&D in 1985, although government provided 47 percent of all R&D funds. Federal laboratories performed 12 percent of all R&D in 1985; colleges and universities, 9 percent; federally funded R&D centers, most of which are administered by colleges and universities, 3 percent; and other nonprofit institutions, the remaining 3 percent.

The 12 percent of R&D performed or managed by colleges and universities deserves additional comment because it includes more than half of all basic research. Until World War II, the universities were not involved significantly in federally funded research. The United States began funding research in educational institutions with the experiment stations at the land-grant colleges in the

Table 3 (Continued)

1978	1979	1980	1981	1982	1983	1984	1985	1986
Million dollars								
$25,976.0	$28,208.0	$29,773.0	$33,735.0	$36,115.0	$38,768.0	$44,214.0	$50,479.0	$58,257.0
12,899.4	13,791.0	14,946.4	18,413.0	22,070.0	24,936.0	29,287.0	34,332.0	42,360.0
2,967.7	3,401.3	3,694.3	3,870.8	3,869.0	4,298.0	4,779.0	5,408.0	5,108.0
2,939.0	3,136.0	2,738.0	3,111.0	2,584.2	2,134.0	2,300.0	1,693.0	3,144.0
3,134.4	3,461.4	3,603.2	3,501.4	3,012.0	2,578.0	2,581.0	2,401.0	2,183.0
1,050.2	1,119.1	1,232.6	1,340.0	1,359.0	1,502.0	1,676.0	1,873.0	1,990.0
767.5	798.2	887.5	869.5	791.0	876.0	1,040.0	1,051.0	952.0
903.9	1,009.6	999.3	1,060.5	965.0	952.0	963.0	1,033.0	905.0
501.3	551.6	585.3	658.5	692.7	745.0	762.0	819.0	778.0
345.1	353.5	468.0	298.4	228.0	189.0	200.0	215.0	210.0
57.2	116.8	127.3	160.0	165.0	177.0	192.0	217.0	225.0
111.1	122.8	125.8	142.9	139.2	157.0	218.0	193.0	187.0
76.7	92.7	102.1	105.5	103.9	106.9	110.0	116.0	106.0
67.3	56.8	77.2	42.6	31.6	32.0	26.0	25.0	24.0
43.7	46.5	45.1	33.8	30.9	37.0	24.0	45.0	40.0
91.9	127.3	119.4	104.3	62.5	44.0	46.0	43.0	28.0
20.3	23.2	22.0	22.1	10.0	5.9	8.0	17.0	18.0
Million constant 1972 dollars[1]								
$17,279.3	$17,256.8	$16,762.2	$17,269.9	$17,252.7	$17,814.5	$19,571.5	$21,546.4	$23,901.3
8,580.7	8,436.9	8,414.8	9,426.1	10,543.2	11,458.5	12,964.0	14,654.0	17,379.2
1,974.1	2,080.8	2,079.9	1,981.6	1,848.3	1,975.0	2,115.4	2,308.3	2,095.7
1,955.0	1,918.5	1,541.5	1,592.6	1,234.5	980.6	1,018.1	722.6	1,289.9
2,085.0	2,117.6	2,028.6	1,792.5	1,438.9	1,184.6	1,142.5	1,024.8	895.6
698.6	684.6	694.0	686.0	649.2	690.2	741.9	799.5	816.4
510.5	488.3	499.7	445.1	377.9	402.5	460.4	448.6	390.6
601.3	617.6	562.6	542.9	461.0	437.5	426.3	440.9	371.3
333.5	337.5	329.5	337.1	330.9	342.3	337.3	349.6	319.2
229.6	216.3	263.5	152.8	108.9	86.8	88.5	91.8	86.2
38.0	71.5	71.7	81.9	78.8	81.3	85.0	92.6	92.3
73.9	75.1	70.8	73.2	66.5	72.1	96.5	82.4	76.7
51.0	56.7	57.5	54.0	49.6	49.1	48.7	49.5	43.5
44.8	34.7	43.5	21.8	15.1	14.7	11.5	10.7	9.8
29.1	28.4	25.4	17.3	14.8	17.0	10.6	19.2	16.4
61.1	77.9	67.2	53.4	29.9	20.2	20.4	18.4	11.5
13.5	14.3	12.4	11.3	4.8	2.7	3.5	7.3	7.4

19th century, but this was too small an effort to alter the nature of the universities. The postwar funding of university research made universities the center of basic research, linking education with research. The share of basic research performed by colleges and universities grew from 25 percent in 1955 to about 50 percent in 1983.

Various Perspectives on Change and Stability One's image of the history of federal R&D support depends on the choice of lens. If one looks closely, federal policy is marked by several significant shifts in priorities and rationale. The spotlight has moved from defense to space to social needs to energy to defense to economic competitiveness, each supported by a different line of argument. A mid-range view shows that defense and defense-related R&D have always dominated federal spending, that R&D to meet social goals has gradually increased, that industry has always performed most U.S. R&D, that universities have

Table 4 Federal Funds for R&D, by Major Budget Function: 1960–1986

Year	Total	Defense	All other	Defense	All other
	Billion dollars			Percent	
1960	$ 8	$ 6	$ 1	81	19
1961	9	7	2	77	23
1962	10	7	3	70	30
1963	12	8	5	62	38
1964	14	8	6	55	45
1965	15	7	7	50	50
1966	15	8	8	49	51
1967	17	9	8	52	48
1968	16	8	8	52	48
1969	16	8	7	53	47
1970	15	8	7	52	48
1971	16	8	7	52	48
1972	16	9	8	54	46
1973	17	9	8	54	46
1974	17	9	8	52	48
1975	19	10	9	51	49
1976	21	10	10	50	50
1977	23	12	12	51	49
1978	26	13	13	50	50
1979	28	14	14	49	51
1980	30	15	15	50	50
1981	33	18	15	56	44
1982	36	22	14	61	39
1983	38	25	14	64	36
1984	44	29	15	66	34
1985 (est.)	50	34	16	68	32
1986 (est.)	58	42	16	72	28

Note: Detail may not add to totals due to rounding. Estimates given for 1986 may change significantly as the result of congressional action on agency budget requests. Data for 1960–77 are shown in obligations; data for 1978–83 are shown in budget authority.

Source: Executive Office of the President, Office of Management and Budget. "Special Analysis K." In *Budget of the U.S. Government, 1986*. Washington, DC: U.S. Government Printing Office, 1985.

gradually become the centers of basic research, and that surges of interest in space or energy do little to alter this generally consistent picture. While heated controversies have occurred regularly, they have always focused on a small part of the federal R&D effort. In the long view, federal R&D has enjoyed broad political support and has grown steadily, except during the late 1960's and early 1970's. One sees a sudden and dramatic shift during World War II, and remarkable resilience since.

Acknowledged Benefits

In evaluating the success of federal R&D, one first must ask what was the purpose for funding it. Because about 75 percent of all federal R&D since the end of World War II was devoted to maintaining national security, winning the race to explore space, and improving our understanding and use of atomic energy, these areas provide the most important criteria for measuring success.

The most apparent benefits come from development projects. The new missiles, aircraft, weapons, detection devices, and computers developed by the Department of Defense in the last 40 years are too numerous to list. Because so much defense R&D is classified, no precise measure of its success is available. The most visible goal of the space program was to be the first nation to put a man on the moon, and the United States did win that race. The successful flight of the Voyager to Uranus and beyond indicates U.S. prominence in unmanned space exploration as well.

In addition to meeting its primary goals, federal R&D in these areas also has affected the development of commercial products. Virtually all defense and space R&D is concentrated in the aircraft, missile, and electronics industries, and these industries have grown quickly because of their sales to government and their development of new products for the private market. According to George Gamota, "The backbone of today's U.S. exports depends on technology mostly started and developed during those early years [of defense R&D]."[5]

The following sections describe some of the acknowledged successes resulting from federal R&D investments in commercial aircraft, biomedicine, physics, chemistry, and education.

Commercial Aircraft The development of military aircraft stimulated advances in commercial aircraft technology. David Mowery points out that development of the jet engine, funded by the military, increased the productivity of commercial airlines dramatically, and other improvements in military aircraft often have been adopted in commercial designs.[6] The Boeing 707 is an adaption of the KC-135 military tanker. The turbofan engine developed by the military for the C-5A transport is the model for the high-bypass-ratio engines that power the Boeing 737-300, 747, 757, and 767.[7]

The benefits to the private sector of military aeronautical R&D are evident in the development costs of Boeing's 707. The McDonnell Douglas Corporation was developing the DC-8 at the same time that the Boeing Company was working on the 707, but Boeing also had the federal contract to develop the KC-135. While McDonnell Douglas wrote off $298 million in development costs and production losses, Boeing wrote off only $165 million. Mowery believes that Boeing's work on the tanker program enabled it to keep its 707 development costs low.[8]

Federal applied research sponsored by the National Advisory Committee on Aeronautics also benefited the private sector directly. In 1927, NACA built the first wind tunnels that could accommodate full-scale airframes, making possible a steady stream of improvements in airframe design. The "NACA cowl" for radial air-cooled engines reduced wind resistance, cutting airframe drag by nearly 75 percent. Also, NACA research led to the development of retractable landing gear and the repositioning of engines in aircraft wings.[9]

The federal government spent $86 billion on aerospace research between 1945 and 1982, while industry was spending $18 billion. Mowery calculates that innovation has saved more than 75 percent of the cost of increasing passenger air traffic since 1939.[10] Thanks to continued federal support, aerospace remains a research-intensive industry, investing 14 percent of the value of 1983 shipments in R&D—a percentage second only to that of the electronics industry. The federal government supplied 74 percent of aerospace R&D funding in 1983.

The commercial value of the R&D investment is reflected in vigorous industry sales. Aerospace was a $76 billion industry in 1983, accounting for more than 2 percent of the gross national product. Its $15.1 billion in exports was the largest single category of U.S. manufactured exports.[11]

Biomedicine Although less heralded than military research during the War, advances in medical technology were one of the outstanding successes of the World War II research effort. In fact, Vannevar Bush gives the war against disease premier status in *Science, the Endless Frontier,* pointing out that Army deaths from disease fell from 14.1 per thousand in World War I to 0.6 per thousand in World War II, largely as a result of penicillin and the sulfa drugs.[12]

Federal biomedical R&D was relatively small after the War, but funding grew quickly after 1960 as policymakers began to look to science for solutions to social problems. Among all the sciences, biomedicine delivers the most visible benefits of basic research. A breakthrough in understanding the nature of a disease can lead directly to treatment and to heartily appreciated benefits to individuals. Rarely can other sciences demonstrate with such clarity the practical outcome of basic research, because the path from basic discovery to application generally is more indirect.

Physics The benefits of basic research in the physical sciences are the most widespread and difficult to pin down, according to Harvey Brooks.[13] The complex path that leads to useful products and the considerable overlap among the physical sciences make it almost impossible to find the source of any stream of innovation. In fact, the scientist doing research in one area of physics is likely to have been trained in another discipline. A 1964 National Research Council survey of doctoral scientists working on solid state physics and electronics in industry found that only 2.5 percent had received their Ph.D. training in solid state physics. Nineteen percent were chemists, and 73 percent studied other areas of physics.[14] Similarly, much of the groundbreaking research in molecular biology in the 1950's and 1960's was done by physical scientists.[15] In other words, the trail is difficult to follow even at the level of basic research.

While the paths of development are not clear, evidence of the role of physical science in making new products possible is plentiful.[16] Sometimes, basic research spurred the development of new tools. The demands of particle physics research, for example, stimulated advances in ultrahigh-vacuum technology, superconducting magnets, and minicomputers. Improvements in beam control techniques at accelerators helped the evolution of electron microscopes, and radiation measurement and safety procedures developed in laboratories are the foundation for nuclear power plant safety standards.

Nuclear physics was basic to the creation of the nuclear power industry and aided the development of radioisotopes and associated radiation detection equipment for use in medicine, agriculture, and industry. Nuclear structure physics and, later, particle physics contributed key insights to astronomy and astrophysics, making possible an understanding of the origin and evolution of the universe.

Atomic, electron, and molecular physics (AME) provided the framework that enabled chemists to develop optical, infrared, and radiofrequency spectroscopy, mass spectrometry, and x-ray crystallography. Indeed, ideas and equipment developed in this field often have been adopted, and often greatly improved and refined, first by chemists and later by biologists and users in other sciences. Quantum mechanics, first tested and refined in atomic, electron, and molecular physics, led to revolutionary changes when applied to chemistry, biology, and biochemistry, according to Brooks. Laser technology, developed in this field, is being applied to earthquake detection, remote monitoring of atmospheric impurities, consumer products, and a host of other uses.

Closely linked to AME, condensed matter physics evolved from solid state physics and provides the foundation for the information revolution based in new computer and telecommunications technology. As vital as condensed matter physics is to electronics technology, however, it cannot claim all the credit for recent advances. Its synergistic interaction with engineering, chemistry, applied mathematics, and other disciplines is the real key to rapid technical progress.

Chemistry Brooks calls chemistry the most pervasive of all the physical sciences, playing a vital role in all the agencies, even NASA, DOD, and DOE, which are closely associated with physics and engineering.[17] Because much of chemical research can be conducted by individuals or small groups with relatively inexpensive equipment, it remains less visible than such disciplines as physics that often require large teams of researchers working with extremely expensive equipment. Lack of visibility does not, however, imply lack of success. In 1965, a National Research Council report, *Chemistry: Opportunities and Needs* (the Westheimer report),[18] studied papers announcing some 40 industrial and pharmaceutical inventions in chemistry since 1946 to uncover their path of development. Reviewing about 750 footnotes, the investigators found that 67 percent of the references for industrial inventions and 87 percent for pharmaceutical inventions were to fundamental science journals. University research was cited 65 percent of the time for industrial inventions and 56 percent for pharmaceutical inventions. Since the government funded 75 percent of academic chemistry research during this period, the Westheimer report provided powerful evidence that federal R&D performed in universities was directly beneficial to the private sector.[19]

Education The scientists and engineers who worked on federally funded research in graduate school could be the most important benefit of the federal R&D effort. Whether in industry, universities, or government, these people are the real source of innovation, but measuring how much federal funds contributed to their education and then how much their education contributed to their later achievements is virtually impossible. Nathan Rosenberg calls this system of funding basic research in universities one of the real strengths of the American R&D system, one that distinguishes it from R&D systems in other countries.[20]

Economic Methodologies

In spite of the abundant anecdotal evidence of the benefits of federal R&D, many policymakers still are puzzled about precisely how to value those benefits. While acknowledging that federal R&D does contribute to the country's well-being, some policymakers want a straightforward economic measure of the benefits. Can we assign a value to the improved military hardware, knowledge of the other planets, newly identified viruses, and computer algorithms that are likely to emerge from federal R&D? Can we go further and identify the commercial products that will emerge from this effort and assign a value to society of those products? If the budget were cut in half, what benefits would be sacrificed? If doubled, could we expect twice the return?

Frequently, R&D programs suffer in comparison with other federal programs because their benefits often are indirect and slow to mature. As Roger Noll and Linda Cohen point out, elected officials prefer programs with immediate payoffs, low risk of failure, and no negative consequences.[21] By these criteria, R&D programs measure up rather poorly: They offer long-term payoffs, are subject to failure, and can lead to the development of socially disruptive new technologies. Voters may be disposed favorably toward federal R&D funding, but Noll and Cohen observe that they vote on the basis of only a few major issues and direct personal interests.[22] To have political weight, therefore, R&D funding must be linked to larger national goals.

For the first time since World War II, U.S. international economic competitiveness is threatened. Technological sophistication has been a vital component of U.S. industrial productivity, and many analysts have argued that scientific research is essential to technological progress. Some policymakers see economic competitiveness as the national issue that will generate public support for R&D spending. To make their argument convincing, they would like to have evidence that federal R&D does improve industrial productivity and yields a net economic benefit for the country. The question is: Do we have the data and the methodology to calculate the economic payoff of federal R&D spending?

Methodologies Estimating the rate of return on federal R&D investment is a small part of a complex field of study that attempts to quantify the impact of numerous factors such as labor and capital on industrial productivity. Peter Reiss points out that economists have yet to agree on a precise measure of the rate of return to private R&D, and the goal is even more elusive for federal R&D.[23] Reviewing the history of economic analysis of R&D, Reiss finds that until the late 1950's economists ignored federal R&D as a factor. Then, a few economists refined their techniques to include federal R&D in such industries as agriculture, mining, and manufacturing. Economists have been less willing to tackle the same question for health, defense, and space research, for which quantifying output is far more difficult.[24] Nevertheless, 25 years of research have produced several approaches to the problem and a better understanding of what is necessary to measure the rate of return to federal R&D.

The traditional economic approach to measuring federal R&D impact is to treat the R&D as an input like capital and to try to isolate its effect on output. The

R&D inputs include ideas, scientists, and equipment, and the outputs are defined more loosely as improved product quality, technological progress, and productivity growth. Quantifying such units presents the first hurdle. Economists usually apply a price index to deflate total R&D expenditures to arrive at a constant price measure for inputs. Similarly, deflated sales data are used to measure outputs.

This information forms the basis for a production function that relates inputs to outputs. In the neoclassical economical model, managers make input decisions on the basis of expected profitability. In evolutionary and behavioral approaches, other assumptions are made about what guides R&D input decisions. Knowing the relationship between inputs and outputs could help guide federal R&D decisions. Calculating the average return to federal R&D is only the first step. Policymakers also want to know how to predict future returns, how to estimate the effect of marginal changes in funding, how federal R&D funding decisions affect private R&D investment, and how that influences productivity. Military R&D might have an average rate of return of ten percent, for example, but a given increase by the Department of Defense in funding aerodynamics R&D might lead a company to shift funds from a commercial project in an effort to win the government contract, possibly affecting productivity.

In looking at federal R&D, one also must pay particular attention to the difference between the private rate of return, which accrues to an individual firm, and the social rate of return, which includes benefits to the entire economy. Policymakers are most interested in the latter, but most R&D studies have focused on the former.

Productivity Analysis The most common approach to the question of R&D impacts is productivity analysis, which assumes that the output of R&D is growth in the production of goods and services. In its simplest form, this approach establishes output as the product of several factors, including the stock of R&D, separated into its private and federal components. Concerned that this approach ignores the economic simultaneity created by input and output decisions, some economists also include a rate-of-change factor. Reviewing such studies, Reiss finds little evidence that federal R&D has a strong direct impact on industrial productivity. He refers to a study by Griliches and Lichtenberg, which found that the rate of return to federal R&D in 27 industries was at most 1.5 percent between 1959 and 1976, while the rate of return to private R&D for the same period was between 9.2 and 33.4 percent. They call this a "gross excess social rate of return" to public and private R&D because it does not include private profits, welfare implications for consumers, depreciation, or adjustments for the overlap among capital, labor, and R&D expenses.[25]

Nestor Terleckyj reports that in several macroeconomic and industry studies he also failed to find a significant direct correlation between federal R&D spending and industrial productivity. Terleckyj argues that, because all companies use federal R&D results until the marginal product is zero, the contribution of federal R&D cannot be identified by traditional statistical techniques.[26]

Robert Weaver argues that we must be careful even with agricultural R&D,

which has been studied extensively and shown consistently robust results. He warns that the nature of the R&D process, the complexity of agriculture decisions, and the dynamic process that separates R&D from the application of research results complicate any effort to measure federal R&D's effect on agricultural production empirically.[27]

Before basing policy decisions on these results, one must evaluate the methodologies used in reaching them. Several questions about productivity analysis remain unanswered. Should federal R&D be treated in the same way as private R&D in production functions? Is there agreement on how to measure the inputs and outputs of federal R&D? Can the method measure rate of return in such major federal R&D areas as defense, health, and space, where quantifying output in economic terms is problematic?

Complementarity Productivity analysis has not established a strong direct relationship between federal R&D and industrial productivity, except in agriculture; it is private R&D that makes the difference. Economists speculate, however, that federal R&D influences private R&D decisions. The trouble with this thesis is that researchers disagree on whether federal R&D spending decreases private investment by substituting for private funds or increases private R&D spending by complementing it and making it more productive.

Frank Lichtenberg suggests that the high concentration of federal contract R&D in a relatively small group of companies and the instability of federal funding could destabilize the market for private R&D output and lower the quantity of R&D in the long run.[28] He also points to several studies that indicate that federal R&D could be crowding out private R&D by raising salaries for scientists and engineers. He refers to a study by Freeman, which found that federal R&D expenditures were the chief source of changes in salaries for physicists and starting engineers since World War II.[29] A survey of college placement officers found that starting salaries for science and engineering graduates rose 8 to 12 percent annually between 1979 and 1984 when the military R&D budget was rising rapidly, but that starting salaries rose only 3 percent in 1985 when military R&D spending stabilized.[30] Salaries are sensitive to demand because the supply of trained labor is fixed in the short run. It takes four to eight years to train a scientist or engineer. In the long run, however, students are very responsive to shifts in demand so that the supply is adaptable over time, keeping salaries from rising too much.[31]

Lichtenberg also points out that rising salaries for scientists and engineers do not mean necessarily that the private sector will do less research. He refers to a study of the impact of the R&D tax credit which found that corporate R&D decisions are not very sensitive to cost. Lichtenberg suggests that if this is true, higher salaries might not reduce private R&D activity.[32]

Reiss's survey of the literature finds general consensus that a complementary correlation exists between federal R&D funding and private R&D.[33] Several studies conclude that a dollar increase in federal R&D spending is followed by an additional 7 to 10 cents of private R&D investment, and one study finds increases as high as 25 to 27 cents for federal R&D performed by industry contractors.[34]

Lichtenberg points out, however, that some of the increased private R&D spending may be aimed at improving a company's competitive position for future government procurements, rather than commercial products, and therefore may not contribute to improved industrial productivity. He found, for example, that government-oriented companies (at least ten percent of sales to the government) were 3.19 times as research-intensive as other companies in 1983.[35] The implication of these findings is that government procurement is a stimulus to R&D.

Lichtenberg tested this thesis quantitatively and found that government procurement is as powerful an influence as government R&D on private R&D. In other words, government procurement and R&D have the same stimulating effect on private R&D, and procurement is more significant because its value is so much larger.[36]

These findings still leave vital questions unanswered. Correlation between increases in federal and private R&D does not prove causation. Both increases could be responses to exogenous factors. And, even if the federal increases are the cause of the private increases, we do not know if this is an average or marginal effect or if the impact is consistent across sector, firm size, and other variables. Finally, the impact may be too small to be significant to policymakers.[37]

Discounted Cost-Benefit Analysis Private firms often use a straightforward cost-benefit analysis to measure the value of R&D. This involves comparing the cost of R&D and the resulting revenues. Once again, assigning a precise dollar figure to these inputs is difficult. In addition, the method has several liabilities in analyzing federal R&D spending. It often measures only the private rate of return—the revenue to an individual firm. While policymakers can benefit from resulting data on private incentives and opportunity costs associated with R&D, they often are more concerned with the social rate of return—the revenues generated in the whole economy. Cost-benefit analysis often ignores indirect effects on other firms, other sectors of the economy, and consumers.

Reiss proposes the hypothetical example of a federal program to increase jet engine efficiency. The firm that wins the contract develops an extraordinarily efficient engine and begins producing a commercial version immediately. The engine is so superior that it dominates the market and drives competitors out of business. The engine price rises because of lack of competition, and the society loses the benefits of innovations that the competing firms might have developed. Cost-benefit analysis would indicate a very successful rate of return to the firm but would not reflect the negative consequences. On the other hand, the analysis also would overlook some benefits. The engine might lead to such large fuel savings for the airlines that they could reduce fares, thus benefiting consumers and business travelers.[38]

Case studies, the standard application of cost-benefit analysis, involve significant conceptual problems. Drawing the line between applicable and nonapplicable R&D determines the cost of the R&D input. One must consider how much unsuccessful R&D to associate with a successful product. As with all rate-of-return methods, one must try to distinguish average and marginal rates of return. Even when a case study is scrupulously correct, it may not provide grounds for generalization. Reiss notes that researchers tend to do case studies on the most and least successful projects, thus limiting their applicability.[39]

Surveys Faced with the numerous uncertainties of quantitative methods, some researchers have turned to surveys of private sector executives to discover how they assess the impact of federal R&D. Reiss recommends a review of surveys by Mansfield, which finds that those surveys uncover important firm-level detail missed by other methods. "Given the limited amount of survey work that has actually been undertaken," notes Reiss, "it is not surprising that this type of research has major limitations."[40] Though finding the approach conceptually straightforward, Reiss concludes that the survey method is expensive, subjective, and especially vulnerable to bias among respondents actively seeking federal R&D funds.[41]

Measurement and Data Concerns All of the econometric methods discussed above share the problem of defining and measuring inputs and outputs and finding the data necessary to make calculations. This fundamental liability undermines the usefulness of all the studies. Workshop participants raised numerous unanswered questions about measuring inputs, including:

- Where does R&D incorporated in a commercial product begin? Is the cost of the Manhattan Project part of the R&D leading up to nuclear medicine?
- What R&D is relevant to a commercial product?
- How quickly does the R&D stock depreciate?
- Does one measure gross or net R&D stock?
- How are the numerous contributors to innovation valued? What weight is assigned to private versus federal R&D?
- What differences emerge in defining inputs for microeconomic and macroeconomic studies?
- Should one assign different values to federal research done in government laboratories, universities, or companies?
- Is the government's definition of R&D the one that should be measured?
- Are overhead, training, information dissemination, and data collection, which are often included in agency R&D budgets, really R&D expenses?

As difficult as it is to measure inputs, the quantification of outputs is even more problematic. Answering the following questions raised in the workshop is only the first step in finding a reliable measure of R&D outputs:

- How is the value of such noneconomic outputs as national security to be measured?
- How are intermediate outputs, such as a mathematical theorem that may eventually contribute to the development of new products, to be valued?
- Where do the outputs of a given R&D project end?
- How are spillovers in unrelated fields identified or evaluated?

- Is there an acceptable measure of output in service industries? Does a count of physician hours worked and beds occupied reflect the output of the health care industry accurately? Do hours available for work measure the value of health?
- Does the price of defense goods represent a market value when it is almost entirely cost-based?

Attempting to identify the costs and benefits of biomedical research illustrates the difficulty of quantifying inputs and outputs. Each research area entails its own ambiguities. Although the benefits of biomedical R&D are apparent, their value is elusive. Jeffrey Harris identifies eight serious unresolved issues in evaluating the economic benefits of biomedical R&D:

(1) The synergistic interaction of basic and applied research makes it difficult to trace the path of innovation.

(2) Similarly, separating public from private R&D is difficult because of their mutual interdependence.

(3) Some biomedical innovations benefit from such diverse nonmedical R&D areas as sonar (ultrasound imaging of internal organs), lasers (retina surgery), fiber optics (direct visualization of internal organs), computational science (CT scanner), and radioisotope and nuclear chemistry (positron emission tomography). Identifying sources is complicated.

(4) Biomedical R&D is so international that foreign R&D must be considered a significant source of innovation.

(5) Improvements in health cannot be attributed automatically to improved technology. Public health measures, environmental conditions, or lifestyle changes might be more important.

(6) Prolonging life can result in significant income transfers from the young to the less productive elderly with poorly understood economic implications.

(7) Economic studies have examined the cost of loss of life but have done little to measure the value of improved quality of life.

(8) Many studies measure returns as gains in productivity, but either the public's willingness to pay for innovations or the profits of private firms might be a more meaningful measure.[42]

Results

The study of economic returns to federal R&D is at an immature stage. According to Peter Reiss, "Current economic measures of returns to federal R&D at most provide crude historical statements about the contributions of federal R&D." He adds that "there are no easy shortcuts that can dramatically improve our methodologies."[43] Harvey Brooks commented during the workshop that the simpler the methodology, the less valid the results, and that some studies are little more than propaganda. Nevertheless, some of the studies have provided valuable information.

The danger lies in using the results indiscriminately. Reiss points out, for example, that comparing results among studies is misleading because they can differ in their use of average or marginal returns, direct or indirect effects.[44] After reviewing economic analyses of space R&D, Henry Hertzfeld warns of the pitfalls in the models: All measured returns are actually partial returns; returns to private R&D should not be compared with returns to federal R&D because their goals are different; the models often do not address the questions about federal R&D that need to be answered; and economic analysis of federal R&D is not a mature art.[45]

During the workshop discussion, Zvi Griliches identified several inherent difficulties in performing economic studies of R&D. Most government R&D goes to projects that produce results with no agreed value, forcing us to turn to spillovers as a measure of value. If we look to the gross national product for indications of increased productivity from federal R&D, we find that government's contribution is measured by its cost, not its value, so that we cannot determine productivity. Improving the national health, for example, increases worker input as well as system output, resulting in no measurable net gain in productivity. Price indices do not reflect improved quality of products, such as the vastly increased computational power of computers.

Peter Reiss and Nathan Rosenberg pointed out during the discussion that the weakness of the data base undermines the usefulness of quantitative results. The major problem is the lack of disaggregated data on the federal R&D budget. The preponderance of defense in the total R&D budget and of development within the defense budget skews the results of any macroeconomic analysis. More detailed data are necessary to produce more useful results.

Griliches commented that economic analyses focus on innovation and productivity gains, overlooking the cost of maintaining the scientific enterprise. A large portion of R&D funding goes to retrieving information and training people to take advantage of that information. Without R&D funding, our technical status would not simply stagnate, it would decline. This is an important economic benefit that is not measured.

While acknowledging the limitations of the studies, one can also see their value. Although there is no definitive measure of rate of return, it is now understood that federal R&D affects productivity indirectly through its effect on private R&D and that federal procurement may be an even more powerful stimulant to private R&D. There is also a better understanding of what constitutes R&D inputs and outputs and a realization that more disaggregated studies are necessary to gain a firm knowledge of federal R&D impact.

The disaggregated studies raise prickly political questions. Some workshop participants want an aggregate measure of the rate of return to federal R&D because budget competition among the agencies is not effective politically. Some believe that Congress is not persuaded to fund R&D by numerous separate appeals. Others argue that the scientific community must be willing to confront the reality of budget limits and make choices among programs. The alternative is for scientists to relinquish some control over research decisions. Roger Noll identifies one way in which this would change R&D policy: Legislators prefer funding a few large projects with highly visible near-term payoffs to funding what many scientists would choose—many small projects with long-term payoffs.[46]

Even if these methodological issues could be resolved, measuring economic returns might not be that useful in evaluating federal R&D. Harvey Brooks observes that the complex interconnections of scientific activity make any simple measure of its value impossible. No economic methodology could capture the benefits of physics to chemistry and biology and subsequently to commercial products. In his view, the path of scientific and technological progress is too indirect and unpredictable to be represented quantitatively.[47]

Several other participants raised the more fundamental objection that economic return is not the purpose of most federal R&D, so that estimating rates of return is misleading. They fear that the use of an economic model for R&D success will skew decisionmaking, that policymakers will pay too much attention to the simple economic measure at the expense of more important, but less quantifiable, criteria for federal R&D.

While acknowledging that economic analysis has produced useful insights into R&D policy and that further analysis could contribute to improvements in R&D policy, the workshop participants agreed on two caveats:

- The models as they now exist have serious shortcomings that limit their application.
- Even if perfected, economic models should be only one of many criteria for guiding federal R&D policy.

Applied Research and Development

Introduction

On the second day of the workshop, Robert White ended his opening remarks with this appeal: "I would hope that we will not spend a lot of time today on trying to define differences between basic and applied research." Many workshop participants reinforced this appeal, and the consensus was that so-called basic and applied research exist on a continuum with no clearly identifiable boundary between the two. Further, several participants provided examples of scientific progress in which the linear model of basic research to applied research to development obviously did not apply. Frank Press cited the phrase "combined mode" research to describe the increasingly common research projects that involve investigators from several disciplines. The phrase could be applied equally well to the blending of basic and applied research.

The issue is not merely a linguistic quibble. Many people oppose government support of applied research in commercial areas because they believe it can interfere with market incentives for private firms to do research. They see applied research as the first step in a federal industrial policy to which they are opposed ideologically. This predisposition against federal support of applied research has created a controversy over the definition of applied research. Instead of debating the merits of a proposed research project, advocates and opponents will argue over whether or not it is applied research, knowing that an applied research label will determine how some political factions will respond to it.

To avoid programmed responses and to move the policy debate away from sterile semantic disputes, this report discusses specific research programs, or research in general, or targeted research when a generic distinction is necessary. The history of federal funding of targeted research supports this departure from the conventional terminology. As Robert White remarked, "I do not think we can talk generally about the federal role in R&D, because I think we do have to look at it almost on a sectoral basis." The United States has funded research on its merits or because of specific political conditions, not according to rigid principles about targeted research.

Roger Noll and Linda Cohen observe that targeted research can win enthusiastic public support because it promises to solve a practical problem, but this can also be a liability. The public expects near-term results, and often the project's success is judged by the market rather than by research managers or scientists. Targeted research runs the risk of visible and politically damaging failure, which limits its appeal to legislators.

In spite of these inherent political liabilities, targeted research in agriculture, health, defense, and aeronautics has enjoyed a long history of support and practical success. In contrast, a few programs, such as the energy efforts of the 1970's, have attracted rancorous debate, and ambitious targeted research proposals from the Kennedy, Nixon, and Carter Administrations have failed to survive the political process. The obvious questions are: How do we account for the varied political success of targeted research programs? What does this tell us about the characteristics essential to acceptance of research initiatives?

The sections below outline the history of federal support of applied R&D in a spectrum of areas and agencies and describe several controversial targeted R&D programs. The final section summarizes some of the issues concerning the federal role.

History

Agriculture Agricultural science was the first governmental venture into systematic targeted R&D. As already mentioned, the Hatch Act of 1887 provided federal funding for research at the agricultural experiment stations associated with the land-grant colleges, which were created in 1862. Policymakers believed that a productive agricultural sector was essential to the country's well-being and understood that farmers could not do their own research. The land-grant colleges also were authorized to do mechanical arts research, but the federal government did not provide funds in that area. Agricultural research remained the largest recipient of federal support until World War II.[48]

Much agricultural R&D is directly responsive to the practical needs of farmers. The large extension program for technology transfer is a two-way effort to give farmers new information and to learn what further information they need. The federal program goes beyond generic research to projects to solve particular farming problems and improve techniques.

Aeronautics The next major federal targeted R&D program was in aeronautics. Congress established the National Advisory Committee on Aeronautics in 1915 to explore the military uses of aviation. After World War I, NACA worked on problems of aeronautics and aerodynamics common to both military and commercial aircraft. The focus of NACA research turned to military airplanes in the 1930's, but it still had a powerful indirect effect on commercial airplane technology.[49]

After World War II, manufacturers took more responsibility for R&D in commercial aircraft, and military aircraft research was funded through the Department of Defense. During this period, NACA limited itself to untargeted, long-term aeronautical research. In 1958, NACA was absorbed into the newly created National Aeronautics and Space Administration, and aeronautical research was slighted in the race to space. A decade later, NASA again turned to such aeronautical problems as aircraft noise and energy efficiency.[50]

The commercial and military usefulness of federal aeronautical R&D has generated broad-based support, which has kept the program alive in the budget-cutting 1980's. In 1981, the Reagan Administration called for deep cuts in aeronautical R&D, but opposition from industry and Congress forced the administration to reconsider. The President's Office of Science and Technology Policy reviewed the matter and released a report in November 1982 supporting continued funding for aeronautical research. While opposing federal funding of civilian technology demonstration, the report called aeronautics a clearly established area of government responsibility.[51]

Health The National Institutes of Health (NIH), the federal agency with the largest basic research budget, in 1985 spent $1.6 billion (more than one third of its total R&D budget) on targeted research and development. Clinical research to classify pathological conditions and find methods for intervention makes up a large share of this R&D. Since 1955, NIH's National Cancer Institute has been developing, screening, and testing drugs with the goal of licensing the patents on the perfected drugs to private firms. Also, NIH has a program to develop "orphan drugs," which treat conditions so rare that they do not attract commercial interest. Other research at NIH played a key role in the development of computerized axial tomography (CAT scans), positron emission tomography (PET scans), and ultrasonic scanning.[52]

Investment by NIH in targeted research and even development of commercial products has attracted little controversy. The public apparently sees health as an appropriate government concern and is happy to receive biomedical innovations from any source. One possible reason that the public views health care differently from other products and services is that 90 percent of all health care bills are paid by insurance companies or the government. Most people, therefore, tend to view health care as a right rather than a commercial product. Public health is seen as a public good, like national security, that has no market value and should be provided by the government or employers.

Energy The government has funded targeted R&D in nuclear power since the 1950's through the Atomic Energy Commission and its successors, the Energy Research and Development Administration (ERDA) and the Department of Energy (DOE). This research included the development and testing of demonstration facilities in the 1950's, and, after 25 years of commercial nuclear power activity, the government still is funding commercially oriented nuclear power research. The program has become increasingly controversial in recent years, with arguments on the safety and economics of the technology itself and on the nature of the government role. Early critics of the program often recommended that the government fund instead the development of alternative energy sources. The fundamental question of the government's appropriate role in energy R&D became an issue only in the 1970's, when government spending increased dramatically to explore a broad mix of technologies, including nuclear fusion, the breeder reactor, solar energy, conservation, and synthetic fuels.[53]

Defense The largest source of R&D funding is the Department of Defense, which spent $2.3 billion on targeted R&D in 1985—more than a fourth of all federal targeted R&D funding. The Department of Defense has been funding targeted R&D since the end of World War II. While most of it has been directed at the development of military technology, commercial spinoffs are common. As George Gamota points out, technology used in semiconductors and integrated circuits developed for ballistic missiles and other weapons systems has been incorporated into computers and other electronic devices.[54] Defense aeronautics research also has been beneficial to commercial products. In fact, DOD has made a deliberate though modest effort to encourage the use of its research results in commercial products.[55]

In some cases, DOD has funded research in technologies already in the commercial market. Research in very high speed integrated circuits, manufacturing technology, and artificial intelligence is linked directly to commercial products.[56] The Strategic Defense Initiative includes planned research in lasers, miniature particle accelerators, and materials that could have widespread commercial applications, according to Gamota.[57]

National Bureau of Standards The National Bureau of Standards (NBS) began to have an important role in R&D for industry in the early 20th century.[58] Albert Teich points out that NBS shifted its emphasis from generic targeted to fundamental research gradually as industry developed its own research capacity, but this trend has reversed recently.[59] Today, NBS is increasing its support of targeted generic research in such areas as materials characterization, processing, and performance, and in fundamental measurements and standards for use in industrial process control and instrument calibration. Metrology research at NBS includes radiation, biotechnology, electronics, optical fibers, and chemical engineering. Other areas of research include building technology, robotics, artificial intelligence, hierarchical control theory, and software engineering. The importance of this work perhaps is most apparent to someone who does not enjoy its benefits. François Lafontaine of the Commission of the European Communities remarked that "the NBS has built the cornerstone of the competitiveness of U.S. industry."[60]

Sources of Controversy

Despite the success of many targeted research programs, efforts to introduce ambitious new programs since 1960 have had little success, and several of the programs that were implemented became embroiled in controversy. Albert Teich's review of these initiatives, summarized below, helps separate what is controversial about targeted research itself from disputes that are particular to the individual programs.[61]

Civilian Industrial Technology Program The success of federal research in defense, aeronautics, and agriculture led the Kennedy Administration to consider federal programs to stimulate innovation in other industries. Administration officials were concerned about the continued growth and competitiveness of the U.S. economy and aware that technology was becoming a key ingredient in industrial progress. A panel of the President's Science Advisory Committee also feared that ambitious defense and space R&D programs were channeling too much scientific and technical expertise into activities with limited commercial application. The administration's economic advisers suggested that federal funding could fill the gap between the private and social rates of return to R&D.

Kennedy appointed J. Herbert Hollomon to the newly created office of Assistant Secretary of Commerce for Science and Technology. Hollomon developed a proposal for a Civilian Industrial Technology Program (CITP), which he expected would eventually grow to be as important as the National Science Foundation (NSF). The goals of the program were to fund university research on industrial problems, fund generic industry research, and improve technology transfer through an extension service modeled on the Agricultural Extension Service. The administration chose textiles, coal, and housing as industries that could benefit immediately from the CITP.

The targeted industries did not necessarily appreciate the special government attention. Teich reports that industry officials maintained that they knew best what R&D was needed and resented being told by Hollomon and other federal officials how to run their R&D programs.[62] Opposition from the supposed beneficiaries of the program doomed the CITP in Congress, which saved only the extension service activities. Congress created the State Technical Services (STS) program in 1965 to increase the flow of technical information to industry through personal contacts, conferences, and other activities. The STS program failed to take hold because it lacked the strong ties to specific research programs that make the Agricultural Extension Service so effective.

New Technological Opportunities Program When the Nixon Administration undertook a review of federal R&D policy in 1971, it came to the same conclusion reached by the Kennedy Administration a decade earlier: Federally funded applied R&D was needed to stimulate economic growth, increase productivity, and improve the country's competitive position. The administration proposed the New Technological Opportunities (NTO) program—an effort even more ambitious than the CITP—under the auspices of the President's Domestic Council and the leadership of William Magruder.

The administration asked federal agencies and a number of companies and trade associations to propose research initiatives. The suggested projects included new nuclear power systems for commercial ships, offshore ports for deep-draft tankers, advanced social communications systems, high-speed ground transportation in the Northeast, and a campaign against kidney disease.

In addition, the NTO proposal included funding for targeted research and generic technology development.

Funding for the projects considered under the NTO program would have cost $11 billion over five years. This large budget and administration doubts about the technical, economic, environmental, and political value of many of the proposed projects forced the administration to reconsider the program, and President Nixon decided against proceeding with any of the proposals.

The 1971 review of federal policy looked beyond R&D to other government technology policies, such as tax credits, patent law, procurement practices, regulations, and antitrust policy. The Nixon Administration decided ultimately to focus on these approaches to stimulating private R&D investment and innovation. The result was two smaller efforts: a National Science Foundation program to study barriers to technological innovation and the Experimental Technology Incentives Program in the National Bureau of Standards to study the effect of federal policies on private sector initiative.

Research Applied to National Needs The National Science Foundation established one other applied research program under the Nixon Administration. In 1969, NSF began the Interdisciplinary Research Relevant to Problems of Our Society (IRRPOS) program with a $13 million annual budget to support projects in universities, national laboratories, and nonprofit research institutions. When NSF submitted its fiscal year 1972 budget request, the Nixon Administration proposed a $100 million increase in NSF's budget to enable it to fund more applied research. The IRRPOS program was transformed into the Research Applied to National Needs (RANN) program with a $34 million first-year budget that rose to $84 million in 1975. The RANN program was controversial from the beginning because its objectives were unclear and its mission did not fit with the traditional mission of NSF. Nevertheless, Teich reported that RANN produced significant results in such diverse areas as alternative energy technologies, fire safety, and earthquake engineering.[63] The program was eliminated in 1978, but many of its projects were continued in NSF and other agencies, particularly ERDA and subsequently DOE.

Cooperative Generic Technology Program President Carter, like President Nixon, ordered a comprehensive review of federal policy to stimulate industrial innovation. The Domestic Policy Review, completed in October 1979, strongly recommended federal funding of university research on industrial problems and federal support for generic industrial research. President Carter included these suggestions in his Industrial Innovation Incentives proposal, which included the creation of generic technology centers. Many of these suggestions were incorporated into the Stevenson-Wydler Technology Innovation Act of 1980, which called for the creation of four generic technology centers, three under the Department of Commerce and one under NSF, as part of the Cooperative Generic Technology Program (COGENT). The government was to provide startup funds, and the centers were to become self-supporting after five years. The Department of Commerce chose powder metallurgy, welding, and tribology as the fields for the three centers. Focusing on technologies used by several industries rather than on specific industries as the Kennedy Administration had done, made the centers more palatable politically. The Reagan Administration, however, had no appetite for programs that moved the government too close to the marketplace, and funding for the centers was cut off before they could be established.

Cooperative Automotive Research Program The Carter Administration had less success in its attempt to establish the Cooperative Automotive Research Program. The idea began in the administration, and auto industry executives were called in later to discuss it. The program aimed at advancing knowledge that could contribute to improving automotive technology. Universities, industry, and federal laboratories were to participate, and industry was to provide some of the funds. President Carter proposed an $800 million federal investment over ten years, and industry was to provide a separate $500 million fund.

Industry, particularly General Motors, gave only grudging support to the initiative, and the administration asked cautiously for just $12 million for the program's first year and waived the industry contribution. President Reagan eliminated funding for the program on the grounds that industry should be doing the research. The fact that most of the auto industry did not object reflected its lack of enthusiasm for the project.

Engineering Research Centers Program The most recent version of federal action to promote industrial innovation is the Reagan Administration's creation of the Engineering Research Centers program in the National Science Foundation. In 1985, NSF funded six multidisciplinary research centers on university campuses, and an additional five or six in 1986. The centers are to do targeted research in areas of direct relevance to industry. Like the COGENT centers proposed by the Carter Administration, each of these centers focuses on a technology used by several industries rather than on a specific industry and strictly eschews product development. George Keyworth, the Presidential Science Advisor, proposed that the government allot $500 million to establish 50 engineering research centers. Science and technology advisers in past administrations have made equally ambitious proposals for similar initiatives, but budget restraints have resulted in drastically reduced results. The continued expansion of the Engineering Research Centers program remains in doubt in the current budget-cutting climate.

Issues

The strongest argument against federal targeted R&D is industry's assertion that government interference disrupts the marketplace and lowers efficiency. Policymakers look foolish promoting a research project aimed at improving industry productivity when leaders of that industry oppose or are indifferent to the effort. While free market advocates generalize about industry opposition to federal research in commercial technologies, the reality is more complex, as the Reagan

Administration learned when it proposed eliminating NASA's targeted aeronautical research program.

Industry Viewpoints Geoffrey Place, for example, sees no room for federal support of targeted research outside of meeting federal agency mission objectives and warns that mission agencies with market responsibility, such as energy and agriculture, should be careful about intruding into the market. He acknowledges, however, that drawing the line between basic and applied research is difficult. His recommendations for research topics deserving federal support include artificial intelligence, lasers, genetic engineering, and computer systems for molecular modeling—all areas that could be called targeted research.

Place recommends an "if it ain't broke" approach to federal involvement in industry-related research, but also observes that one explanation for Japanese success is their relentless drive to improve products. Place believes that American companies, by comparison, are quite complacent. He implies that U.S. industry must abandon its own "if it ain't broke" strategy if it is to compete successfully in an age of rapid technological progress. This raises difficult questions: Should government step in where industry is intransigent? Can the government stimulate innovation in that situation?

Robert Hirsch recommends a more activist role for government in energy R&D. A member of the Department of Energy's Energy Research Advisory Board (ERAB), Hirsch says that he and the other ERAB industry members have recommended, at the end of an 18-month study, that the government has a responsibility to develop technologies to help the country reduce foreign oil dependence and to assure an adequate supply of economical, safe, and environmentally acceptable electrical power. To ensure the usefulness of federal R&D, Hirsch calls for increased industry participation in federal R&D planning. Finally, Hirsch suggests that in some circumstances the government should go beyond research to fund demonstration projects, usually in cost-sharing arrangements with industry.

Hirsch makes it clear that the targeted research debate is not simply a battle between industry and government officials. Noting that critics of government R&D programs often point to synthetic fuels as an area where government wasted money because it did not understand the market, Hirsch observes that the private sector also spent billions of dollars in synfuels R&D. Neither government nor industry is infallible, he concludes, and they might be most effective working together.

Gerald Laubach believes that federal biomedical research policy, which has given primacy to the support of basic biomedical science through NIH, has been spectacularly successful and productive but that other federal policies have hindered the application of research results.

Norman Abramson points out that nonprofit research centers have been doing targeted research for government and industry since World War II with relatively little controversy. Southwest Research Institute, for example, does 40 percent of its work for government agencies and the remainder for the private sector. These centers emphasize multidisciplinary problem-solving and pay special attention to technology transfer. Most important, says Abramson, they demonstrate that government can fund R&D in a cooperative setting with industry without creating political problems.

Related Federal Technology Policies While industry leaders disagree on how far government should go in R&D with direct commercial applications, they speak with one voice in saying that tax policy, regulations, and patent protection are more important considerations in technological progress. Gerald Laubach argues that the regulation of medical R&D and the "so-called procompetitive" restructuring of American health care often prevent the full utilization of the benefits of biomedical R&D. He recommends a holistic policy approach. Geoffrey Place adds that the government must work for tighter international patent protection and standard regulations to prevent technology piracy that deprives U.S. firms of the benefits of their R&D investment. Norman Abramson recommends tax policies that encourage R&D investment and antitrust policies that allow cooperative research within an industry.

David Mowery observes that the regulatory policies of the Civilian Aeronautics Board (CAB) played a decisive role in technical innovation in the commercial airlines.[64] Because CAB controlled fares, the airlines were forced to compete in quality of service, and new technology was one of the characteristics the airlines promoted. Federal regulations to improve automobile emission control technology, on the other hand, did not stimulate innovation because every manufacturer had to meet the same standard, and there was no comparative advantage to be gained. The industry therefore collectively resisted the standards and delayed their implementation.

Harvey Brooks points out that regulations play a crucial role in the adoption of federal research results. He mentions price supports in agriculture, the third-party payment system in medicine, phone rate controls in telecommunications, the protected market for military weapons, and utility rate control in the period before 1970 when electrical generation costs were declining. In virtually every instance that federal R&D is considered successful, regulatory and other government policy played a complementary role in supporting an assured demand for the innovative products or services.

Reasons for Failure How does one explain the success and popularity of most federal targeted research in light of the oft-repeated maxim that the government should stay out of such research? A few very visible and controversial programs have given federal applied research a bad name, but Albert Teich points out that many of the most notorious federal efforts never got off the ground. The Kennedy, Nixon, and Carter proposals discussed earlier never became major programs. Others, such as the supersonic transport, Morgantown personal rapid transit system, and Operation Breakthrough (an effort to develop innovative, low-cost housing) attracted plenty of attention but relatively little federal money. Teich calls these political, not technical, failures.[65]

Teich, citing analyses by John Logsdon and Harvey Averch, suggests that such programs as the Civilian Industrial Technology Program, New Technological Opportunities, and Industrial Innovation Initiatives failed to win political support because they sought support on the ideological grounds that government must solve broad economic problems instead of relying on the market.[66] The technical merits of the proposals were forgotten in the ideological furor, and they failed to win support because they went against the grain of American free market beliefs.

Having reviewed the fate of these failed research proposals, Teich suggests some technical and political guidelines for framing applied research initiatives to make them more palatable politically and more effective technically:[67]

- Define goals modestly.
- Tailor the program to fit the structure of the target industry.
- Match user needs and research institution capabilities.
- Emphasize generic research, leaving product design and commercialization to the private sector.

Just as some targeted research programs failed to win support for the wrong reasons, several won extensive federal funding for the wrong reasons. Roger Noll and Linda Cohen observe that because the Clinch River Breeder Reactor became symbolic of government support for nuclear power, it received funding long after the changed economic environment had undermined the original justification for a short-term breeder commercialization program.[68]

More Than Ideology The federal role in research, which often is discussed as an ideological question about government intrusion into the marketplace, actually is a more complex question of how to structure government research programs. First, research cannot be divided easily into separate stages. Second, the crucial criterion for research with commercial applications is not its ideological correctness but its appropriateness to the specific industry or industries it aims to serve. Third, the success of research in stimulating innovation is dependent on the full range of government policies affecting the target industry. Fourth, targeted research initiatives must walk a political tightrope, balancing the promise of near-term payoffs with technical realities, ambition with the risk of failure, dispersed benefits with project control.

Federal targeted research has a long history of support and success and a recent history of controversy and disappointment in a few highly visible programs. Often, the ideological terms in which the debate is framed cloud the real issues. Pragmatic criteria outweigh philosophical concerns in the final analysis, and the politics of research will be more constructive when those involved can focus on details of specific programs, including the industrial and policy environments in which they must operate.

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Appendix 1 Workshop Participants

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F. Karl Willenbrock, Cecil H. Green Professor of Engineering, Southern Methodist University

Appendix 2 Commissioned Papers

Energy Research and Development, John F. Ahearne, Resources for the Future

Returns on Federal Investments: The Physical Sciences, Harvey Brooks, Harvard University

Impact of Defense R&D Investments on the Civil Sector, George Gamota, University of Michigan

Biomedical Research and Development: Measuring the Returns on Investment, Jeffrey Harris, Massachusetts Institute of Technology

Measuring the Economic Impact of Federal Research and Development Investments in Civilian Space Activities, Henry R. Hertzfeld, Consultant

The Government Role in Research and Development: What Other Nations Are and Are Not Doing—The European Community Case, François Lafontaine, Delegation of the Commission of the European Communities

Assessing the Impact of Federal Industrial R&D Expenditure on Private R&D Activity, Frank R. Lichtenberg, Columbia University

Federal Funding of R&D in Transportation: The Case of Aviation, David C. Mowery, Carnegie-Mellon University

Economics, Politics, and Government R&D, Roger G. Noll, Stanford University, and Linda R. Cohen, University of Washington

Economic Measures of the Returns to Federal R&D, Peter C. Reiss, Stanford University

A Historical Overview of the Evolution of Federal Investment in R&D Since World War II, Nathan Rosenberg, Stanford University

✓✓ *Federal Support of Applied Research: A Review of the United States Experience,* Albert H. Teich, American Association for the Advancement of Science

✓✓ *Measuring Economic Effects of Federal R&D Expenditures: Recent History with Special Emphasis on Federal R&D Performed in Industry,* Nestor E. Terleckyj, National Planning Association

✓✓ *Federal R&D and U.S. Agriculture: An Assessment of Role and Productivity Effects,* Robert D. Weaver, The Pennsylvania State University