Federal Support for R & D and Innovation

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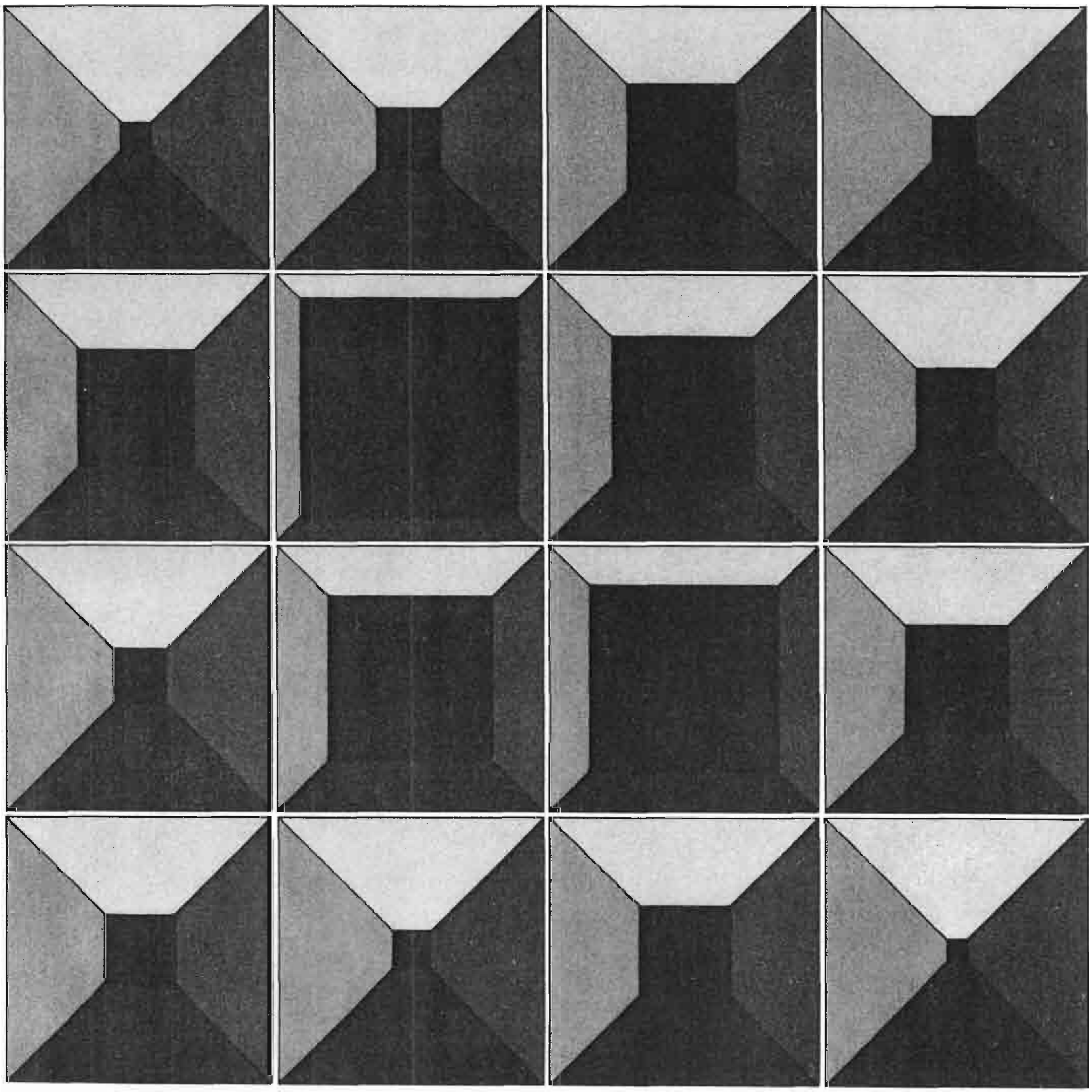

FEDERAL SUPPORT FOR R&D AND INNOVATION

The United States Congress
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PREFACE

Innovation plays an important role in economic growth, so that increased innovation is one means whereby current economic problems can be overcome. The government affects the innovation process in two main ways. First, it shapes the environment in which private firms make decisions about innovation. Second, the government funds roughly half the research and development (R&D)--a necessary condition for innovation--carried out in the U. S.

At the request of the Senate Budget Committee and the Senate Committee on Commerce, Science, and Transportation, the Congressional Budget Office has prepared an analysis of the underlying issues affecting innovation policy and of current programs in this area. This report supplements the detailed analysis of current R&D budget proposals that is provided by the CBO special study, Research and Development Funding in the Proposed Fiscal Year 1985 Budget. In keeping with CBO's mandate to provide objective analysis, the paper offers no recommendations.

The report was prepared by Louis Schorsch of CBO's Natural Resources and Commerce Division under the direction of David L. Bodde and Everett M. Ehrlich. Teresa Dailey and Joel Jacobsen carried out valuable research. The author also wishes to recognize the contributions made by Jeffrey Nitta of CBO's Budget Analysis Division and Elliot Schwartz and Philip Webre of CBO's Natural Resources and Commerce Division. Professor Edwin Mansfield of the University of Pennsylvania, Albert Teich of the American Association for the Advancement of Science, and Gregory Tassey of the National Bureau of Standards provided helpful comments on the first draft of the report. Patricia H. Johnston edited the manuscript. Philip Willis typed the early drafts, while Kathryn Quattrone typed later drafts and prepared the report for publication.

Rudolph G. Penner
Director

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CONTENTS

		Page
PREFACE	. . . .	iii
SUMMARY	. . . .	xi
CHAPTER I.	INTRODUCTION.	1
	The Potential for Increased Innovation.	1
	The Government Role: R&D Investments and Private-Sector Incentives	3
	Plan of the Report	4
CHAPTER II.	UNDERSTANDING INNOVATION AND R&D: THE PUBLIC AND PRIVATE ROLES	5
	Innovation and R&D: A Complex Relationship	6
	The Different Actors in the R&D Process and Their Roles	10
	Aggregate Patterns of R&D Expenditures in the United States	17
CHAPTER III.	R&D AND ECONOMIC PERFORMANCE . . .	27
	Measuring the Return to R&D	27
	R&D and Economic Competitiveness	31
	U. S. R&D Expenditures Within an International Context	44
CHAPTER IV.	CURRENT TRENDS IN R&D SPENDING . . .	51
	Overview	51
	R&D Spending by Agency	56
	Output-Based Descriptions of Federal R&D Spending	61
	Recent Trends in Private R&D Spending	69

CONTENTS (Continued)

		Page
CHAPTER V.	GOVERNMENT ENCOURAGEMENT OF INNOVATION: TAX AND OTHER POLICIES	71
	Tax Policies	72
	Antitrust Policy	83
	Patent Policy.	85
	Procurement Policies	86
CHAPTER VI.	IMPROVING FEDERAL SUPPORT FOR R&D AND INNOVATION	89
	What Role for Government?	89
	Policy Options	93
APPENDIX A.	R&D INTENSITY AND INTERNATIONAL COMPETITIVENESS: METHODOLOGY . . .	105

TABLES

		Page
TABLE 1.	ESTIMATED RETURNS TO R&D EXPENDITURES.	29
TABLE 2.	R&D INTENSITY IN SELECTED INDUSTRIES FOR 1960, 1970, AND 1981. . .	33
TABLE 3.	R&D INTENSITY AND INTERNATIONAL COMPETITIVENESS FOR SELECTED YEARS	35
TABLE 4.	R&D INTENSITY FOR CORPORATE AND GOVERNMENT FUNDING BY INDUSTRY FOR 1960, 1970, AND 1981 . . .	38
TABLE 5.	TOTAL AND DIRECT R&D INTENSITY FOR THE 1977-1979 PERIOD	40
TABLE 6.	HIGH TECHNOLOGY SHARE OF U.S. MANUFACTURING SHIPMENTS AND EXPORTS, EXPORT SURPLUS SHARE OF EXPORTS, AND IMPORT SHARE OF APPARENT CONSUMPTION, 1974-1981 . . .	44
TABLE 7.	NOMINAL AND REAL PATTERNS OF R&D SPENDING BY TYPE AND CATEGORY, FISCAL YEARS 1980, 1982, AND 1984 . . .	53
TABLE 8.	FEDERAL BASIC AND APPLIED RESEARCH FUNDING, BY FIELD OF SCIENCE FOR CALENDAR YEARS 1967, 1980, AND 1984.	64
TABLE 9.	ESTIMATED FEDERAL FUNDING OF SPECIFIC TECHNOLOGIES BY MAJOR R&D AGENCIES, FISCAL YEARS 1980 AND 1983.	67

TABLES (Continued)

Page

TABLE 10. ESTIMATED PRIVATE R&D SPENDING AS A PERCENT OF SALES, CALENDAR YEARS 1979-1982 70

TABLE 11. ESTIMATED TAX REVENUES FOREGONE BECAUSE OF THE INCREMENTAL R&D TAX CREDIT 79

APPENDIX TABLE

Page

TABLE A-1. PRODUCT FIELD CATEGORIES, U.S. SIC CODES AND SITC CODES: 1980 106

FIGURES

		Page
FIGURE 1.	FEDERAL, PRIVATE, AND TOTAL R&D, 1953-1982	18
FIGURE 2.	R&D AS A PERCENT OF GNP, 1953-1982	18
FIGURE 3.	TOTAL R&D BY TYPE, 1953-1982	19
FIGURE 4.	PRIVATE R&D BY TYPE, 1953-1982	19
FIGURE 5.	FEDERAL R&D BY TYPE, 1953-1982	19
FIGURE 6.	R&D BY PERFORMER, 1953-1982	22
FIGURE 7.	BASIC RESEARCH BY PERFORMER, 1953-1982	22
FIGURE 8.	APPLIED RESEARCH BY PERFORMER, 1953-1982	22
FIGURE 9.	TOTAL RESEARCH BY PERFORMER, 1953-1982	22
FIGURE 10.	DEVELOPMENT BY PERFORMER, 1953-1982	22
FIGURE 11.	SOURCES OF UNIVERSITY R&D FUNDS	23
FIGURE 12.	FEDERAL R&D BY BUDGET FUNCTION, 1953-1980	24
FIGURE 13.	FEDERAL R&D BY AGENCY (OBLIGATIONS), 1956, 1964, 1972, AND 1980	24
FIGURE 14.	FEDERAL R&D FUNDING BY INDUSTRY FOR 1957, 1969, AND 1981	39

FIGURES (Continued)

Page

FIGURE 15. REAL R&D FUNDING IN SELECTED COUNTRIES, 1961-1980 46

FIGURE 16. R&D AS A PERCENT OF GNP IN SELECTED COUNTRIES, 1961-1980 46

FIGURE 17. CIVILIAN R&D AS A PERCENT OF GNP IN SELECTED COUNTRIES, 1961-1980. 48

FIGURE 18. U.S. TRADE IN LICENSES AND FEES, 1967-1982 48

FIGURE 19. FEDERAL FUNDING BY FIELD OF SCIENCE, 1984 63

FIGURE 20. REAL GNP AND REAL PRIVATE R&D, 1961-1981. 74

SUMMARY

Current economic problems have drawn attention to the potential benefits that increased innovation, the introduction of new products and processes, could bring to the U.S. economy. More rapid rates of innovation could boost productivity growth, improve the international competitiveness of American industry, and provide the new industries needed to offset the poor growth prospects of mature sectors.

THE GOVERNMENT'S ROLE IN IMPROVING INNOVATION

The innovation process is too complex to be amenable to direct government action. Instead, the government seeks to foster innovation by establishing conditions conducive to innovative activity, an effort that combines two aspects:

- The government funds roughly half of the research and development (R&D) that is carried out in the United States. Although not identical with innovation, R&D provides the scientific and technical advances needed to sustain rapid rates of innovation. The fiscal year 1985 budget request calls for close to $53 billion in total government R&D funding, up from $44.5 billion in 1984.

- The government shapes the environment in which the private sector makes decisions about its own R&D and about the innovations it will pursue. This environment comprises overall macroeconomic conditions as well as the specific programs affecting private-sector innovation, such as tax incentives, antitrust restrictions, and so on.

The Government's Role in Funding R&D

The substantial government subsidies provided for research and development are justified on the grounds that the government should support R&D projects that are socially desirable but that are unlikely to be funded by private firms. The R&D needed for national defense is the outstanding example of activities for which the government assumes responsibility. As a result, defense accounts for a large and increasing share of the federal research budget. Since the rationale for government funding of defense-related R&D is relatively unproblematic (although the level and composition of such funding may be controversial), this report concentrates on the issues involved in civilian R&D funding and the general economic goal of more rapid rates of innovation.

Many of the policy choices in the innovation area depend on one's view of whether the market provides adequate incentives for private firms to fund the R&D needed to sustain rapid rates of innovation. When incentives are inadequate, it may be the government's responsibility to provide funding. How one defines the boundary between private and public responsibility shapes one's attitude toward policy proposals aimed at fostering innovation.

Traditionally, the public and private roles in civilian R&D have been defined in terms of what this report calls the "pipeline concept." According to this view, R&D is the core of the innovative process, and it comprises a continuum of basic research, applied research, and development. In essence, these categories can be described in the following terms:

- Basic research refers to scientific activities undertaken without regard to practical considerations, akin to "pure" science. Its results are generally uncertain, long-term, and unlikely to remain the property of the organization that sponsors the research. The investigations typically undertaken at university laboratories are good examples of basic research.

- Applied research denotes scientific activities that are undertaken to address practical problems rather than to expand the frontiers of knowledge. The defining difference between basic and applied research, therefore, concerns goals rather than content.

- Development refers to activities undertaken to solve the technical problems involved in bringing a new product or process into production. Engineering, rather than scientific activities, typically predominate in development.

As conventionally interpreted, these categories make up a linear process that runs from basic research through applied research to development. The process can be viewed as a pipeline: funds invested in basic research lead to new insights that can be focused by means of applied research and then commercialized through development. The pipeline concept also suggests a division of responsibilities between the public and private sectors. Commercialization (development and the steps that follow it) can for the most part be left to private industry, while the government's role is to subsidize basic research, which is too far removed from commercial considerations to receive adequate corporate support. According to the pipeline concept, government funding of basic research eventually leads to the commercial innovations that underlie improved economic performance.

Despite the widespread acceptance of the pipeline concept, the federal government has frequently funded civilian development activities, such as the projects designed to develop alternative energy sources and thus contribute to energy independence. Although such activities have received substantial funding, they remain outside the traditional interpretation of the government's role in R&D funding.

The pipeline concept and its concomitant definition of the public and private roles offer little guidance concerning the government's role in applied research. Some observers compare applied research to development and view market incentives as adequate to ensure sufficient private R&D funding. Others extend the rationale for public support of basic research to applied research as well, arguing that the private sector may underfund both forms of research.

How to define the government's role in applied research is one of the most significant questions facing policymakers seeking to increase the return on government-funded civilian R&D. Those who support a strong governmental commitment to applied research frequently question the view of the innovation process that underlies the pipeline concept, emphasizing the importance of the activities that link science and commerce.

The Government's Role in Shaping the Environment for Innovation

Regardless of the level of government R&D funding, the technological performance of the economy--the rate at which it develops and adopts innovations--depends on the actions of private firms. The government cannot dictate this process; it can only indirectly influence the innovative performance of the private sector. Some of the policies that shape the economic environment affecting R&D and innovation are listed below.

- **Macroeconomic policies.** In a growing economy, firms have increased cash flow to invest in R&D and greater confidence about the expected return to long-term and uncertain R&D projects. Macroeconomic policies that boost investment are particularly important in diffusing the innovations embodied in new capital equipment and increasing the incentives for innovation in capital-goods industries.

- **Policies affecting competition.** Competition is a strong inducement to innovation, since new technologies are an effective means of reducing costs and opening new markets. Policies that restrict competition, such as trade barriers, also reduce the incentive to innovate.

- **Tax incentives.** Besides the general tax policies that are an important component of macroeconomic policies, specific tax incentives have been implemented to encourage R&D and innovation.

- **Regulatory policies.** Government regulations can affect the rate of innovation. Environmental regulations may have required the commitment of R&D resources to pollution control rather than to productivity-enhancing projects. Antitrust regulations may keep firms from pursuing joint R&D projects that are unlikely to be undertaken by individual companies. Finally, patent policies, especially those involving rights to the results of government-funded R&D projects, also affect the rate of innovation.

- **Institutional and informational support.** The government can also influence the rate of private-sector innovation by providing information concerning technological developments and by facilitating links between business and the scientific community. The Department of Agriculture's technical support programs are a good example of such policies.

R&D, INNOVATION, AND ECONOMIC PERFORMANCE

While there are no explicit measures of innovation in the economy, proxies such as the rate of productivity growth suggest that the rate of innovation has slowed in the 1970s. The declining competitiveness of major U.S. industries, such as steel and automobile production, stems in part from a deteriorating U.S. technological advantage. Evidence indicates that even those manufacturing industries that are very technologically advanced and are net contributors to the balance of payments are losing competitive ground rather than retaining their lead over foreign producers. Since the late 1970s, however, the private sector has increased its commitment to R&D, and this may portend improved technological performance.

International competitiveness is highly correlated with R&D funding: firms that devote a small portion of their revenues to R&D tend to be poor competitors internationally, while firms that are strongly committed to R&D tend to be highly competitive in global markets. This relationship can be interpreted in two ways. Greater R&D investments may be a cause of good performance, so that increased R&D spending might improve the performance of less technology-intensive industries. Alternatively, industries that tend to be poor competitors internationally may be characterized by technologies that are played out, so that the return to R&D is low. These divergent interpretations of the close relationship between R&D and international competitiveness make it difficult to focus federal R&D policies to deal with the challenge of intensified international competition.

Government R&D spending by industry is also closely correlated with an industry's international competitiveness, which indicates that the pattern of government spending helps to shape the prospects of different industries. This correlation suggests that "low-tech" industries might benefit from some reorientation of federal R&D support by industry. Moreover, the waning competitive performance of several of the U.S. economy's "high-tech" sectors suggests possible technological weaknesses in the economy as a whole, a judgment that may warrant a reevaluation of governmental innovation policy. This problem may reflect a lack of aggressiveness on the part of U.S. manufacturers in adopting foreign innovations. It may also reflect the fact that countries like Japan and West Germany devote a significantly greater share of their gross national product (GNP) to civilian R&D. Policies that address such issues in order to improve the technological performance of key sectors of the U.S. economy could potentially alter the sectoral structure of the U.S. balance of payments. It should be pointed out, however, that reductions in the net imports of some sectors would be offset by countervailing shifts in the trade balance of other sectors.

Government efforts to improve the economy's technological performance should recognize that general conceptions of the innovation process fail to capture its industry-specific characteristics, which may be the most significant factors determining technological performance. In some cases, large firms in concentrated industries have outstanding records of innovation, while in others the same features are associated with relative technological stagnation. In many emerging industries, small firms are the source of rapid rates of innovation. In general, the record seems to show that innovation will be greatest when firms have the funds to invest in R&D--either because they are large or because they have access to capital markets--and when competition is strong. In addition, many other factors affect the technological prospects of specific industries: the extent to which basic science is carried out in related areas (in ferrous metallurgy for steel production, for instance), the size of the market, the capital-intensity of the industry, and the extent of technological competition in the industry. The interaction of these factors can determine the effectiveness of government innovation policies. For example, tax incentives that increase innovation in one industry may have little effect in an industry that lacks the basic research foundation needed for rapid rates of innovation. In the latter case, direct governmental funding of basic research may be a more appropriate policy initiative than tax incentives.

CURRENT R&D POLICIES

Since 1980, significant changes have occurred in the pattern of government R&D spending, as the Administration has reaffirmed the traditional rationale for governmental R&D funding. In the Administration's budget request for fiscal year 1985, defense-related R&D accounts for almost 70 percent of the total R&D budget--the highest share since 1962. In terms of civilian R&D, the Administration has reoriented spending towards basic research, which increased 23 percent in real terms between fiscal years 1982 and 1984. Civilian applied research and development have had their real funding cut almost in half since 1980. Cuts have been particularly severe at the Departments of Energy, Commerce, and the Interior, and at the Environmental Protection Agency (EPA)--although the EPA R&D budget was increased sharply in the 1985 budget request.

The Administration's R&D effort relies on the private sector to compensate for the government's reorientation of its civilian R&D funding away from applied research and development. The Administration has sought to elicit increased private R&D through a strong economic recovery, specific R&D incentives, and the removal of some barriers to private R&D. Since the late 1970s, private R&D spending has been quite strong, although the trend predates the change in Administration.

Recent changes in the tax laws, especially the accelerated capital recovery system (ACRS), have increased the attractiveness of investment, and this should speed the diffusion of innovations and increase the rate of innovation in capital-goods industries. ACRS's effects on R&D are complex, however, since the program reduces the relative impact of the R&D tax incentives that were in effect prior to the passage of the Economic Recovery Tax Act (ERTA) of 1981. Nevertheless, the net impact of ACRS on R&D incentives now appears to be positive.

In addition, ERTA introduced an incremental tax credit for increases in R&D expenditures. This program is scheduled to expire in 1985, and its impact is limited by several of its features. While the net impact of this program is positive, large numbers of firms are unable to make full use of the credit, either because they have limited tax liabilities (due to unprofitability or start-up status) or because the increases in their expenditures exceed the cap included in the program. The option of "expensing" labor and material costs for R&D, which has been in effect since 1954, is a more significant incentive than the incremental credit. 1/

Finally, the Administration seeks to encourage greater private-sector R&D by eliminating some of the regulatory barriers to such activity, especially at the basic research end of the R&D spectrum. This is the rationale behind efforts to relax antitrust restrictions on R&D joint ventures.

POLICY OPTIONS

Policymakers' attitudes toward specific innovation policies depend upon their view of the government's role in funding R&D and encouraging private innovation. Alternatively, this question can be defined in terms of the adequacy of incentives for private-sector R&D and innovation. Clarifying this underlying issue could place specific R&D policies on a clearer and more coherent foundation. Some specific options for improving federal R&D and innovation policies are discussed below.

R&D Funding. The effectiveness of governmental R&D funding depends on several factors: the stability of funding, the mix of R&D funding by type, the mix of R&D funding by industry, and so forth.

- The R&D budget could be appropriated for longer than a single year. Since R&D projects are both long-term and risky, short-term volatility in funding undermines the effectiveness of such projects.

- Greater attention could be paid to the mix of spending by type and particularly to the adequacy of funding for civilian applied research. Some of the savings from reductions in civilian development projects could be devoted to increased basic and applied research.

- The pattern of federal R&D support by industry could be made more explicit, so that the Congress could better decide whether adequate funding is available across the economy. Savings could be gained from tying government subsidies to matching funds from industry.

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1. Expensing means that firms can deduct the full cost of qualified R&D expenditures in the year that the expenditures are made rather than depreciating them over a number of years.

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- Major scientific projects, such as the superconducting super collider and the manned space station proposed in the fiscal year 1985 budget request, are increasingly expensive. Their costs could be reduced by encouraging greater international cooperation in such projects.

Tax Policies. R&D tax incentives could be strengthened. One means to this end would be to extend the incremental R&D tax credit. Some changes in this program could increase its incentive effects: the amount of the credit could be raised, the base expenditure could be calculated in real terms, the cap on the allowable increase could be eliminated or made less strict, and so on. The evidence concerning the effectiveness of the incremental R&D tax credit is mixed, however, so that its extension may not generate the benefits its proponents seek.

Antitrust Policies. So long as adequate safeguards for competition remain in place, relaxing antitrust restrictions for R&D joint ventures could encourage greater private support for research. Initiatives such as this may be particularly important if government funding for civilian applied research continues to be reduced.

Patent Policies. The Congress could consider supporting the Administration's efforts to grant patent rights to the firms that perform government-sponsored R&D. Evidence suggests that government retention of rights serves to retard innovation rather than to increase government revenues.

Institutional Arrangements. New institutional arrangements might be particularly important if the Congress wishes the government to play a more active role in encouraging industrial innovation. New institutional arrangements might require only limited government involvement; the Administration, for instance, is seeking to encourage closer relations between universities and industries without major government expenditures. More fundamental institutional changes could include government sponsorship, with private cooperation, of applied technology centers or the establishment of a National Technology Foundation, akin to the National Science Foundation. Both these approaches have been contained in proposed legislation. Such institutional reforms might be an appropriate vehicle for improving the government's support for applied research and for better adapting innovation policies to the specific technological needs of different industries.

CHAPTER I. INTRODUCTION

Current interest in innovation and in research and development (R&D) reflects their potential for providing technological improvements to help solve the problems that have plagued the U.S. economy since the early 1970s. The economy's poor performance over the past decade includes relatively slow rates of growth, high rates of unemployment and inflation, and deteriorating international competitiveness in some key industries. More fundamental trends, such as lagging productivity growth and a less fluid pattern of industrial output, have been cited as underlying causes of more evident economic problems. 1/ Against this background, increased innovation stands out as a promising means of contributing to the revitalization of the economy.

THE POTENTIAL FOR INCREASED INNOVATION

Innovation represents the introduction of new products and processes, and it can run the gamut from the development of minor refinements in traditional products to the seminal breakthroughs in technology that initiate new industries. In some cases, innovations are the product of expensive, long-lasting, and risky projects that rely on large numbers of scientists and engineers, as did the Manhattan project. Private industry relies increasingly on a similar approach to innovation; the scientific and technical expertise marshalled by semiconductor and bioengineering firms are popular contemporary examples of this phenomenon. This is not the only path to innovation, however. Highly significant innovations, such as the introduction of the assembly line, can result from organizational or managerial changes.

The factors that affect the rate of innovation are both highly complex and inadequately understood; innovation is rooted in the still unexplained relationships among intellectual inspiration, scientific discovery, and perceptions of market opportunity. For economic theory, technological change and innovation have been treated as a "black box." One can measure the inputs into the process and identify the new products and processes that result from innovation, but what happens inside the black box remains

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1. See Congressional Budget Office, The Productivity Problem: Alternatives for Action (January 1981); and The Industrial Policy Debate (December 1983).

murky. What determines the rate at which new ideas are commercialized? Is technological progress the product of the resources devoted to scientific and engineering activities, or does such progress depend crucially on elusive and still unquantifiable properties such as "entrepreneurship?" While such issues cannot be definitively resolved, they do suggest that policymakers should be wary of simplistic solutions to the complex problems of increasing innovation and improving the economy's technological performance.

Once innovations are disseminated throughout the economy, they provide three main benefits:

- Innovation increases productivity. New processes--such as continuous casting in steelmaking or numerical control in metalworking--directly increase productivity. Moreover, productivity growth tends to be most rapid for new products, which characteristically become cheaper and better designed as they experience rapid market growth.

- Innovation boosts the international competitiveness of American industry. The comparative advantage of U.S. firms increasingly lies in their ability to remain near the cutting edge of new technology. Industries that are technologically intensive, such as data processing, still enjoy a significant trade surplus, while industries that invest relatively little in new technologies, for example, steel, are less competitive internationally.

- Innovation provides the foundation for emerging industries. Because of relatively stagnant demand and increased international competition, many of the mature industries in the U.S. economy are unlikely to generate significant long-term increases in employment. New industries, many of which will use new technologies, are needed to provide employment and income, compensating for the poor growth prospects of mature sectors.

Innovation is not a panacea, however. The introduction of new technologies inevitably involves some adjustment costs. New technologies often require new skills, for which the labor force must be trained, and alter the pattern of output, reducing employment and income in technologically stagnant sectors of the economy. Nevertheless, these adjustment costs do not outweigh the potential benefits of technological progress, which is an underlying source of higher living standards and improvements in the quality of work.

THE GOVERNMENT ROLE: R&D INVESTMENTS AND PRIVATE-SECTOR INCENTIVES

Because innovation itself is difficult to measure, discussions of this subject typically focus on more measurable proxies, such as the funds devoted to research and development (R&D) or the number and significance of patents issued to innovators. No proxy adequately captures all of the factors that affect innovation. Nevertheless, R&D data are less problematic than other measures. Moreover, R&D spending is relatively amenable to government action, since the government funds roughly half the R&D carried out in the U.S. For these reasons, this report devotes a great deal of attention to R&D. R&D is not synonymous with innovation, however; and policymakers cannot assume that increased R&D spending will inevitably lead to increased innovation or improved technological performance in the economy as a whole.

R&D is a relatively recent label for an ancient activity: the purposeful expansion of knowledge and its application to commercial pursuits. R&D expenditures measure a society's commitment to fostering technological progress, although other conditions must be met if R&D is to lead to widespread innovation. From an economic point of view, R&D is an investment, and innovation, with all its economic benefits, is the return on that investment. There are reasons other than economic benefits for governmental support of R&D: national prestige, the maintenance of an outstanding educational system, national security, and so on. While such goals are worthwhile, the focus of this report is the economic importance of R&D and innovation.

For various reasons, private firms are likely to underinvest in R&D, especially in R&D activities that do not have a clear and immediate commercial potential. The government can ensure that R&D investment is adequate by directly funding socially beneficial activities that the market is unlikely to support.

In addition, the government has the more diffuse responsibility of ensuring that the economic environment is conducive to private-sector investment in R&D and, more generally, to innovation itself. The rate of innovation is primarily determined by the activities of private firms. At the very least, effective innovation policy requires an awareness of the ways in which government policies, such as trade restraints or antitrust restrictions, may affect private-sector innovation. More actively, the government can also provides incentives, particularly through the tax system, to boost private-sector R&D.

Direct R&D funding and the maintenance of incentives for private-sector innovation are the two main elements of federal innovation policy. Many other federal programs also affect the technological performance of the economy, however. Education policies, for instance, influence the availability of qualified scientists and engineers, the ease with which innovations will be adopted by the labor force, and the overall social attitude towards science and technology.

PLAN OF THE REPORT

This report is designed to provide a background against which the Congress can evaluate specific policy initiatives in the innovation area. A complementary CBO report discusses the treatment of R&D programs in the budget submission for fiscal year 1985. 2/

Chapter II discusses the links between R&D and innovation and defines the roles played by the different actors in the innovation process. Chapter III presents evidence on the relationship between R&D and economic performance, emphasizing international competitiveness. Chapter IV presents an overview of current trends in R&D funding. Chapter V discusses government incentives (other than direct funding) for private-sector innovation, concentrating on tax expenditures, which have the most immediate budgetary impact. Finally, Chapter VI presents some policy options in the areas of innovation and R&D.

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2. Congressional Budget Office, Research and Development Funding in the Proposed Fiscal Year 1985 Budget (March 1984).

CHAPTER II. UNDERSTANDING INNOVATION AND R&D: THE PUBLIC AND PRIVATE ROLES

While the underlying subject of this report is the government's role in fostering innovation, measuring and directly influencing innovation itself is difficult. This shifts the emphasis of innovation policy to related areas, particularly to investments in research and development (R&D). Throughout the postwar period, R&D has accounted for between 2 and 3 percent of GNP--not counting the unreported activities of independent investors and entrepeneurs--and is thus "big business" in its own right. More importantly, however, it is the bridge between science and production, and over this bridge pass most of the new products and processes that generate economic growth. This chapter provides a background for understanding the role of R&D and the responsibilities of the participants in the R&D process--government, industry, and the scientific community.

Both the general economic benefits of governmental R&D support and the roles of the different actors in the R&D process are conventionally defined in terms of what this report calls the "pipeline concept": the government funds the apractical activities of the scientific community, which are then commercialized through several steps by the private sector. There are exceptions to this pattern, of course. For example, the government funds a great deal of practically oriented research in agriculture, for which there is a long history of federal R&D support. Nevertheless, the pipeline concept has helped shape the pattern of civilian R&D activity in postwar America, as will be shown in the data presented in the final section of this chapter.

In many ways, the division of labor based on the pipeline concept has served the economy well. Insofar as the Congress is interested in improving technological performance in the economy as a whole, however, it may be worthwhile to reconsider some of the underlying assumptions that inform current R&D policies. In particular, the following points should be more widely recognized:

- The innovation process is highly industry-specific, in terms of both the level of R&D support and the nature of the obstacles to improved technological performance. General policies, therefore, fail to address many factors affecting innovation.

- R&D is best understood as a complex, interactive process rather than the unidirectional series of steps suggested by the pipeline concept.

- The most crucial policy issue in the R&D area concerns the public and private roles in funding activities that link pure scientific research with the concerns of the marketplace. The pipeline concept offers little guidance on this issue.

- The scientific community, which exercises a significant degree of control over science funding (especially through the National Science Foundation), may not pursue the same goals as the Congress. Specifically, the priorities of the scientific community are not based on economic potential.

INNOVATION AND R&D: A COMPLEX RELATIONSHIP

Focusing on R&D renders innovation a more tractable problem for policymakers, but these activities are not identical. R&D is a necessary but not sufficient condition for rapid rates of innovation. The economic fruitfulness of R&D ultimately depends on the private sector, whose initiative in turn depends upon macroeconomic conditions and upon a variety of factors that are highly industry- and firm-specific.

The traditional analysis of technological progress, first suggested by Joseph Schumpeter, identifies three steps: invention, innovation, and imitation.[1] Invention denotes the discovery of a new process or product and the resolution of associated technical problems. Innovation refers to the transformation of invention into a commercially usable process or salable product, including market research and promotion. Imitation denotes the process whereby an innovation is diffused through an industry or, in the case of a breakthrough technology like computers, through many industries. Such diffusion has a dual aspect: other producers can replicate an innovation, and more users can adopt it. It is important to recognize that even an innovation that is highly significant in a technological sense has limited economic impact until the imitation or diffusion process is fairly advanced.

While Schumpeter's analysis is a provocative first approximation, it fails to portray adequately the complex network that links laboratory

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1. Joseph A. Schumpeter, Business Cycles (New York: McGraw-Hill, 1939), especially Chapter III.

research and commercial results. A more comprehensive breakdown might include the following steps, not all of which are necessary for every innovation:

1. Basic laboratory research;
2. The identification of potential commercial applications;
3. The assessment of technical feasibility;
4. Applied research;
5. The preparation of product specifications;
6. Construction of a prototype or pilot plant;
7. Tooling and construction of manufacturing facilities;
8. Initial manufacturing and marketing;
9. Reassessment of commercial potential; and
10. Licensing and so forth, leading to widespread imitation. 2/

This list suggests the complex procedures that must be followed if the insights of research and development are to be transformed into usable products and processes. In a market economy, the prospect of entrepreneurial profits is the principal glue holding this sequence together. Conversely, conditions that undermine this incentive--from insurmountable technical problems to poor market prospects to inadvertent government interference--can weaken, or even atrophy, the links between R&D and the market. Although R&D is only part of the innovation process, it is amenable to direct government funding, while the other elements depend more on the initiative of private firms and, therefore, on the overall economic environment. As a result, R&D can be treated separately from the other activities that are essential to the broad economic processes of invention, innovation, and diffusion.

Because R&D itself refers to several different types of activities, aggregate measures of R&D spending convey only a limited amount of information about the economic potential of government funding. Since its founding, the National Science Foundation (NSF) has sought to deal with this problem by breaking down R&D activities into basic research, applied research, and development. These categories have played a major role in determining government R&D policy for the past 35 years. NSF defines these categories as follows:

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2. This list is partially based on Edwin Mansfield, "Determinants of the Speed of Application of New Technology," in B. R. Williams, ed., Science and Technology in Economic Growth, (New York: John Wiley, 1973).

- **Basic research.** For the federal government, universities and colleges, and other nonprofit institutions, basic research is directed toward increases of knowledge in science with ". . . a fuller knowledge or understanding of the subject under study, rather than a practical application thereof." To take account of an individual profit-making company's commercial goals, the definition for industry funding is modified to indicate that basic research projects represent ". . . original investigations for the advancement of scientific knowledge . . . which do not have specific commercial objectives, although they may be in fields of present or potential interest to the reporting company."

- **Applied research.** The NSF states: "Applied research is directed toward practical application of knowledge." Here again, the definition for the industry survey through which NSF collects private-sector data takes account of the characteristics of industrial organizations. It covers ". . . research projects which represent investigations directed to discovery of new scientific knowledge and which have specific commercial objectives with respect to either products or processes."

- **Development.** The concept of development used in the NSF survey may be summarized as ". . .the systematic use of the knowledge or understanding gained from research directed toward the production of useful materials, devices, systems or methods, including design and development of prototypes and processes." 3/

As this breakdown is conventionally interpreted, basic research, applied research, and development represent a continuum of activities that stretch between pure science and the market. Within this channel, or pipeline, basic research is practically identical with pure science, while the most short-term and incremental development projects are hardly distinguishable from the constant refinement and improvement of techniques that characterize any production process. Since R&D activities can be located along this continuum according to their proximity to the market, an implicit division of labor between the public and the private sectors emerges from the pipeline concept, with the government funding those activities farthest from the market. The breakdown of R&D into these three categories also can be used to provide a rough indication of the functional mix of programs

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3. National Science Board, Science Indicators 1980 (Washington, D.C.: U.S. Government Printing Office), p. 254.

receiving governmental support. For these reasons, this categorization of R&D has sunk deep roots into the administration and interpretation of R&D policy.

There are at least two types of risks inherent in excessive reliance on this conventional breakdown of R&D activities, however. The first stems from the fact that these categories tend to overlap in practice. This introduces some arbitrariness into any quantitative disaggregation of R&D expenditures. In many cases, the allocation of specific projects between basic and applied research or between applied research and development is a highly subjective judgment. As a result, applied research is inevitably a problematic category.

The second and more serious deficiency of this conventional categorization concerns the extent to which the perception of a linear R&D continuum confuses the actual linkages among the different types of R&D activities. It suggests that there is a pipeline running from the laboratory to the market: basic research leads to applied research leads to development leads to new products. In reality, however, the relationships among these categories are much more interactive and fluid. Insofar as the distinctions among these categories become institutionalized, the conventional breakdown of R&D may well be counterproductive, artificially restricting the practical applications of scientific research as well as depriving scientists of the feedback that can provide a foundation for inductive theoretical advances. 4/ Moreover, the increasing tendency to view R&D as a form of investment undermines the usefulness of the distinction between basic and applied research. Other ways of categorizing research projects--perhaps one that emphasizes the synergy between a project's basic and applied aspects--may be worthwhile alternatives to the rigid structure of an R&D continuum. 5/

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4. Researchers at Bell Labs, for instance, cite that institution's grounding in practical problems as a principal reason for its outstanding performance in fundamental science. See "Bell Labs; Threatened Star of U. S. Research," Business Week, July 5, 1982, p. 48. Medical research, which typically links fundamental scientific work with practical goals, is another provocative example.

5. See Donald Stokes, "Perceptions of the Nature of Basic and Applied Science in the United States," in A. Gerstenfeld, ed., Science Policy Perspectives: USA-Japan (New York: Academic Press, 1982).

While it is impossible to evaluate patterns of R&D funding without reference to the categories of basic research, applied research, and development, it is important to emphasize that these distinctions are crude--not just because of definitional overlap but also because of the dubious linear concept of the R&D continuum itself. In addition, the pipeline concept alone is not an adequate guide for determining the appropriate level of governmental support for applied research.

THE DIFFERENT ACTORS IN THE R&D PROCESS AND THEIR ROLES

One of the reasons for the pipeline concept's durability--despite the fact that it oversimplifies the role of R&D in the innovation process--is that it can be used to provide a relatively clearcut definition of the proper roles for the different actors in the R&D process. Once a project has reached the actual stage of commercialization (whether of a new product or a new process), the private sector plays the major role. Similarly, development activities that are closely related to the market can be left to the private sector. Earlier in the process, however, there is reason to believe that the market will fail to support R&D adequately and that government should compensate for this failure.

Government: The Justification for Public Support

In recent years, the federal government has funded about 45 to 50 percent of the R&D carried out in the United States. Federal commitments of this magnitude--almost $45 billion in fiscal year 1984--are justified by reference to two distinct types of market failures. The less problematic concerns "public goods"--those technologies of which the government is the principal purchaser. The second argument favoring governmental funding of R&D is based on the alleged inadequacy of the R&D carried out by the private sector, mainly because private businesses are generally unable to retain all the economic benefits of the R&D that they fund. (In economic jargon, this inability to keep all the benefits of R&D is called "nonapprobriability.")

Since public goods are consumed collectively, they must be purchased by the government, which is, in effect, identical with the market for these goods. In such cases, the government can either produce the good itself or issue purchasing contracts to private producers. In either case, the costs of production must be borne by the government.

Defense is the archetypal public good. When the government contracts for defense goods, such as new weapons systems, it also purchases the necessary R&D, which is an integral part of their costs. Since the government, as sole or principal purchaser, specifies the desired properties of the eventual product, this kind of federally funded R&D has generally been effective, at least in terms of meeting technological goals. The government has developed methods to ensure that private firms selected to produce public goods have the necessary scientific and technical understanding to do so. This has been true not only in the defense industry but in other areas as well--for example, space exploration.

Federally funded R&D targeted toward public goods has generated some serendipitous civilian benefits. Examples of such "spinoffs" can be found in the computer and semiconductor industries, the aerospace industry, and so on. Such civilian applications are minor, however, when compared to federal R&D investment in public goods. Furthermore, since the government may require product characteristics that differ from those preferred by civilian consumers, it may be difficult for government contractors to commercialize their R&D. Semiconductor firms, for instance, often relied on defense contracts when this industry was being established. Yet the most successful of these firms eventually made a conscious effort to change their marketing approach in order to cultivate the potentially larger civilian market and reduce their reliance on government contracts.

Federal R&D funding in areas that are not linked to public goods is justified by a different argument--namely, that the private sector underinvests in R&D. This argument is based on the view that R&D is characterized by positive "externalities"--that is, costs and benefits that are not captured in market transactions. In the case of research, the total (or "social") benefits exceed the private benefits, implying that less of this "good" is produced (in other words, less research is carried out) than is socially desirable. As a result, there is a basis for government intervention to subsidize research, either directly or through the tax system.

Private firms pursue innovations either because they reduce the cost of production, in the case of process innovations, or because they open new markets, in the case of product innovations. The prospect of increased profits motivates this process, and the profits that accrue to an innovating firm depend on the extent to which the benefits of the innovation can be retained by the firm. Once the results of research enter the market, however, successful imitation is almost certain, despite patent protection. A firm carrying out research must accept the fact that its competitors either will gain some of the benefits produced by its research or will, at the very least, force down the price of a new product before the innovating firm has exhausted its potential for generating innovator's profits. An automaker, for instance, might recognize a significant market for more fuel-efficient engines yet still not invest large sums in basic or applied research because it also believes that any advances it makes are likely to be copied by its competitors, so that the returns to such research would be inadequate.

Innovator's profits, however, are only part of the social return, which also includes additional imitators' profits and the gains that consumers enjoy, per dollar spent, as a result of the innovation. This implies that social welfare will be increased by government support for R&D projects with low private returns and high social returns. While this discrepancy is difficult to quantify, it is likely to be greatest for activities that are only tenuously connected to the market and that generate results which are easily imitated by competing firms. These characteristics are especially relevant to basic research.

Several studies have attempted to quantify the alleged discrepancy between the private and social benefits of R&D. While such estimates must cope with significant conceptual and informational problems, they generally suggest that the social benefits of R&D exceed the private benefits captured in market transactions. One cross-industry analysis, for instance, found a median social rate of return to R&D of 50 percent, while the median private rate was 25 percent. 6/ Although it should be pointed out that this study found extensive variation in rates of return among industries, a pattern of significantly greater social benefits was widespread. Such evidence supports the argument that government funding is needed because the private sector will underinvest in R&D, particularly research.

Private Business

The private sector is the key actor in the innovation-diffusion process. Businesses carry out most of the development work that is a necessary complement to government-supported research. Even large amounts of government money spent on worthwhile civilian research projects will have no impact unless their results lead to commercial innovations by private companies and unless these innovations are used. Commercialization, in turn, depends on private firms' assessment of an innovation's potential profitability in the face of uncertain technological and marketing prospects.

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6. Edwin Mansfield, et al., "Social and Private Rates of Return from Industrial Investment," Quarterly Journal of Economics, 91(2) (May, 1977), pp. 221-240.

This assessment has both an objective and a subjective aspect; it depends not only on the costs and benefits of an R&D project but also on a firm's willingness to take risks and its commitment to a dynamic, technology-based competitive strategy.

Even if one accepts the view that the government should be responsible for supporting the nation's basic research effort, the impact of such support as well as the level and quality of private R&D efforts depend on the environment in which firms make decisions about R&D investments. Some of the features of a supportive environment tend to be noncontroversial: a growing economy, for instance, encourages R&D and speeds the diffusion process. Macroeconomic policies, which are discussed in Chapter V, therefore significantly influence R&D and innovation. Other features of an optimal R&D environment are linked to market structure, which the government regulates through the anti-trust system.

According to one view, relatively concentrated industries, dominated by large firms, are more likely to have the financial resources, the expertise, and the strategic perspective needed to support R&D and to manage the innovation process. R&D is characterized by some economies of scale, and large firms are able to diversify the risk inherent in R&D by funding a variety of projects. Certainly, there are numerous examples which support the hypothesis that large firms are the most effective innovators. AT&T, IBM, and Dupont, for instance, traditionally devote significant resources to R&D and have outstanding records of technological performance. Such firms are stable enough to support basic research as well as product development.

At the same time, there are numerous examples of industries that are highly concentrated and yet have a record of poor technological performance, raising doubts about the hypothesis linking innovation to large firms in concentrated industries. Different examples have been cited to support the view that innovative activity will be strongest in less concentrated industries such as computer software, in which competition ensures that successful firms must stand near the technological frontiers. According to this view, there are disincentives to innovation for large firms in concentrated industries. Such firms may seek to protect the asset values embodied in existing equipment, for instance, or they may fear that the benefits of R&D are likely to be rapidly eroded by strong competitors. These conflicting views of the links between market structure and the innovation process suggest that diverse government policies may be needed to encourage innovation by the private sector (for example, diversity in antitrust enforcement or in the use of tax incentives).

The effect of various market structures on innovation has been studied extensively. Economists have failed to prove or disprove either of the conflicting hypotheses, suggesting that the actual process of innovation is too complex to allow analysts to determine that one market structure or one firm size is generally more conducive to innovation. 7/ Instead, a more complicated pattern emerges. The results seem to suggest that innovation is likely to be strong in an industry made up of several relatively large firms, so that two conditions are met: firms have both the resources to carry out R&D and the incentive to innovate because of interfirm rivalry. Thus, innovation seems to be fostered by a market structure that avoids the extremes of monopoly and atomistic competition.

The most important implication of this research, however, is the understanding that the factors affecting innovation are industry-specific, so that general policies are likely to be less effective than ones adapted to the characteristics of a given industry. The potential for innovation--and the obstacles to the realization of that potential--depend on factors such as:

- The absolute size of the potential market;
- The potential of the technology itself;
- The vitality of the scientific disciplines that provide the foundation for the industry's R&D effort;
- The extent to which the innovation is embodied in plant and equipment, so that it can be purchased by domestic or foreign competitors;
- The extent to which technological competition has traditionally characterized the industry; and
- The vulnerability of the market to international competition.

These different characteristics influence the potential effectiveness of different government policies. Broad-based tax incentives, for instance, may not generate significant innovative activity in an industry that suffers

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7. For a summary of this literature, see Morton I. Kamien and Nancy L. Schwartz, "Market Structure and Innovation: A Survey," Journal of Economic Literature, 13(1) (1975), pp. 1-37. The same authors expanded and updated this analysis in Market Structure and Innovation (Cambridge, England: Cambridge University Press, 1982).

from a weak scientific base. In such a case, federal funding for related research may be a more appropriate policy, while tax incentives may lead to a waste of resources on minor refinements or on conservative projects that are duplicated by a large number of firms.

The potential for duplication in private-sector R&D efforts raises doubts about the validity of the traditional assumption that the private sector will underfund R&D. While this assumption has a convincing logic in aggregate terms, it may not hold true for the mix of private R&D spending among basic research, applied research, and development. The potential for private R&D spending greater than the socially optimal level is greatest in the development projects that are closely linked to the market. This consideration suggests that an increase in aggregate R&D spending need not imply a change in the rate of innovation. As a result, federal programs that encourage higher levels of private R&D may bring greater benefits if they also address the mix of private activities. Here again, the competitive characteristics of individual industries may be more relevant than aggregate measures.

The Scientific and Engineering Community

The third major actor in the R&D process comprises the scientists and engineers that actually carry out research and development. Institutionally, R&D scientists and engineers can be found at government labs, corporate research facilities, and nonprofit organizations, particularly universities. For a variety of reasons, universities are the cornerstone of this community: they carry out significant amounts of R&D for the government and for private firms, they are frequently linked with industrial and government laboratories (particularly the national labs), and they provide most of the formal education that trains all the members of the scientific and engineering community.

While universities fund very little R&D, they carry out well over half of the nation's basic research and thus play a pivotal role in the R&D effort. Their dependence on external sources of funds implies a governmental responsibility to ensure that adequate resources are available for carrying out significant research, especially if one accepts the view that advances in basic research are the original source of new products and processes. Just as importantly, funding university research is also an aspect of the government's educational responsibilities. While industrial laboratories may be able to carry out the same research programs as do universities, they do not and probably cannot play the same educational role. Without a healthy university research climate, government and industry are unlikely to find

39-373 O - 84 - 3

the qualified scientists and engineers needed to undertake R&D outside the academic environment.

In terms of R&D itself, the role played by the scientific and engineering community raises two other issues that deserve mention. The first concerns the extent to which scientific research can be viewed within a strictly national context. A unique set of circumstances--particularly the intellectual diaspora provoked by fascism and war in Europe--allowed the United States to dominate the world of science after 1945, just as it dominated the world economy. International competition is now a problem for many U.S. industries that once had a competitive advantage, and policy initiatives--including increased R&D support--are being considered to re-establish the competitive prowess of American manufacturing. An analogous goal is often stressed for science, so that the increased scientific capabilities of Europe and Japan are viewed as a challenge.

This is a false analogy. Economic performance and technological progressiveness are determined not by the quality of a nations' science but by the rapidity and sophistication with which scientific advances are transformed into commercial products and processes. The contrast between scientific and economic performance in Britain and Japan supports this judgment. The increased scientific efforts of other countries should be welcomed as a potential source of advances that can be adopted and exploited by American industry, balancing the traditional postwar flow of scientific knowledge from this to other countries. Seeking to restore the scientific hegemony enjoyed by the United States in the early postwar period would be prohibitively expensive. Moreover, it would probably be impossible, since scientific advances tend not to respect national boundaries. Greater international scientific cooperation could play an important role in increasing the tempo of scientific progress and boosting the growth prospects of the world economy. From an economic point of view, the key goal in R&D policy should not be to reestablish U.S. scientific dominance but rather to reestablish the U.S. economy's traditional aggressiveness in commercializing scientific advances.

The second major policy issue connected with the role of the scientific and engineering community concerns the potential discrepancy between scientific and national goals. Traditionally, the pattern of federal support for basic research has been greatly influenced by the priorities of the scientific community. To the Congress and society at large, R&D is primarily an investment good. That is, funding is provided for R&D as a roundabout route to achieve socially desirable goals, such as the elimination of disease, increased employment opportunities in nonmenial professions, the development of safe products and production processes, and so on. For the scientific community, however, R&D is generally viewed as a consumption good; that is, the ideal scientist is one who pursues scientific knowledge for its own sake. This means primarily basic research, which is apractical by definition. Hence, policymakers must recognize that the priorities of the scientific community are not necessarily identical with the government's policy goals. 8/ It would probably be counterproductive to bureaucratize the R&D effort, allowing nonspecialists the final say in evaluating and thus controlling specific scientific projects. It may be just as counterproductive, however, to assume that the specialist community will structure the R&D effort in order to maximize social, as opposed to parochial, benefits. The distinction between the consumption and investment aspects of R&D should be given a prominent place in assessing the purposes and prospects of the federal R&D effort.

AGGREGATE PATTERNS OF R&D EXPENDITURES IN THE UNITED STATES

The final section of this chapter discusses the general features of R&D spending in the United States over the past 30 years, emphasizing how spending patterns reflect the division of labor discussed above. It first describes the sources of funds, after which it turns to the performers of R&D and a more detailed assessment of trends in federal R&D funding. As much as possible, spending levels are presented in real terms, using the implicit GNP price deflator to adjust nominal spending levels. 9/

Sources of Funds

Figures 1 through 5 illustrate historical trends in the overall pattern of R&D spending in the United States. Figure 1 shows that real R&D

8. This argument is presented in more depth in B.R. Williams, "The Basis of Science Policy in Market Economics" in B.R. Williams, ed., Science and Technology in Economic Growth (New York: John Wiley, 1973).

9. The data used here are drawn from the National Science Foundation, which is the principal government collector of information relating to the national R&D effort. It is important to emphasize that these data are estimates, particularly in regard to private-sector R&D funding. In addition, the GNP price deflator may understate increases in the cost of carrying out R&D. That, at least, is the conclusion drawn by several authorities, although there is no consensus about a more appropriate R&D deflator.

Figure 1.

Federal, Private, and Total R&D, 1953-1982

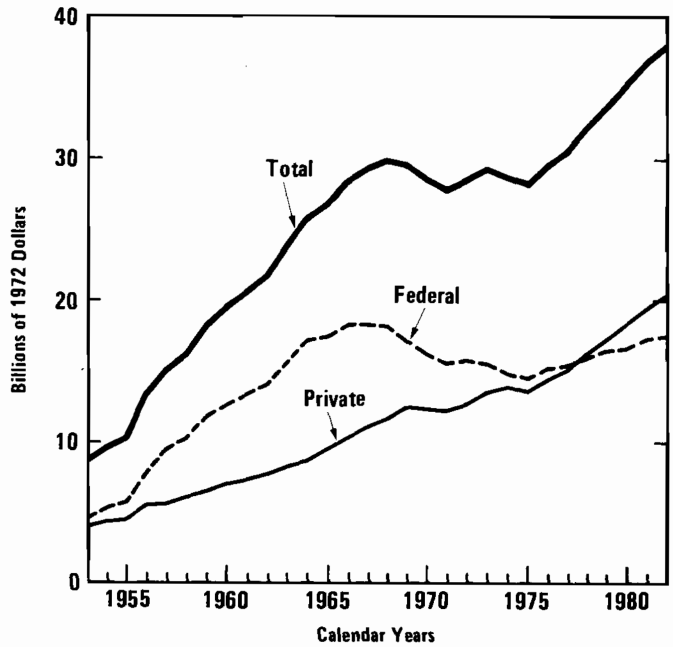
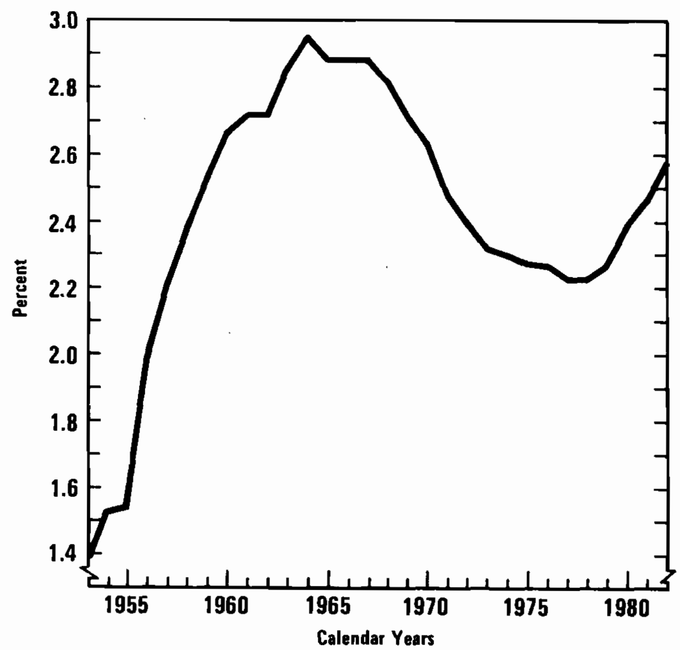


Figure 2.

R&D as a Percent of GNP, 1953-1982



SOURCE: National Science Foundation.

Figure 3.
Total R&D by Type, 1953-1982

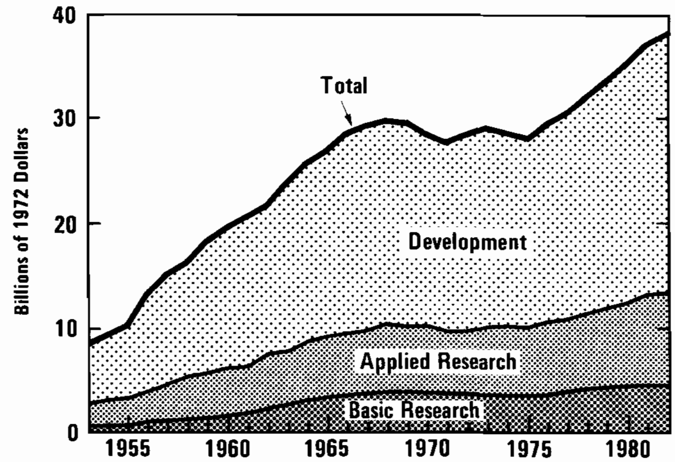


Figure 4.
Private R&D by Type, 1953-1982

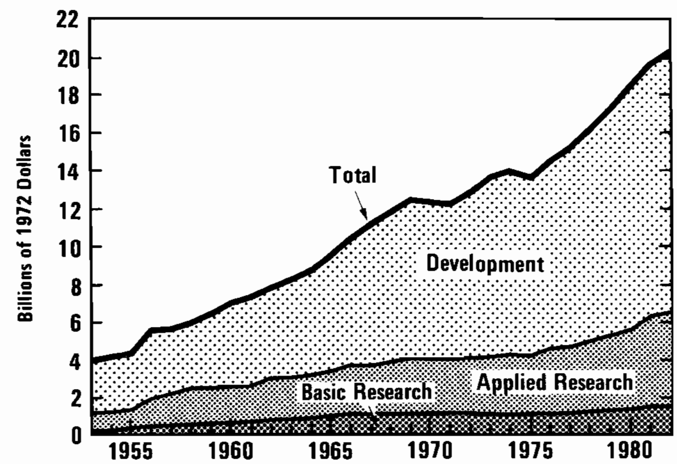
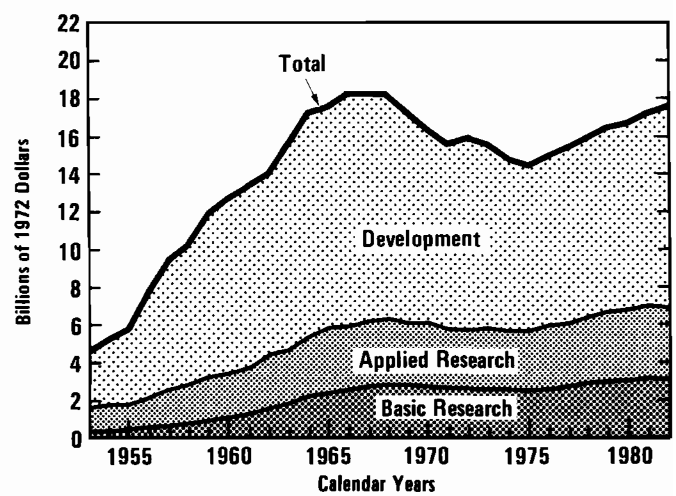


Figure 5.
Federal R&D by Type, 1953-1982



SOURCE: National Science Foundation.

expenditures have tended to increase gradually, if somewhat unevenly, over this period. Within this general pattern, however, several features stand out. Overall R&D spending increased at a real annual rate of 8.5 percent during the 1950s and 1960s (1953-1968). Total spending declined slightly in real terms from 1969 to 1975, and since that year it has increased at a real annual rate of 4.4 percent.

These aggregate results were the product of different sectoral forces. Through the 1950s and 1960s, the overall growth in real R&D spending was driven by both government expenditures, which rose at a compound annual rate of 10.2 percent, and private R&D funding, which increased at a rate of 7.8 percent per year. From 1968 to 1975, declines in federal R&D funding were only partially offset by private-sector increases, leading to the observed weakening in overall spending. Finally, both federal and nonfederal spending have increased in real terms since 1975, the latter more rapidly than the former (6.3 percent vs. 2.8 percent from 1975 to 1982).

Despite the relatively steady growth of R&D spending, its share of economic activity has been highly variable, rising from a little more than 1 percent in the immediate postwar period to a high of almost 3 percent in the mid-1960s and then declining from the mid-1960s to the late 1970s (see Figure 2). Shifts in R&D's share of the gross national product (GNP) are largely caused by changes in the level of federal R&D support. Industry's proportional commitment to R&D--its "R&D intensity"--has been much more stable throughout the postwar period. Over the past 5 years, R&D's share of GNP has risen at a healthy rate, although it should be pointed out that this is at least partially due to slow GNP growth.

Figure 3 presents a cumulative breakdown of overall R&D spending, according to the traditional categories of basic research, applied research, and development. This figure suggests the extent to which development activities dominate basic and applied research, an outcome stemming from the fact that commercialization is generally more expensive than science. Moreover, such data suggest that development funds have also been more volatile than funding for research.

Constant-dollar R&D expenditures by industry exhibit a relatively smooth upward trend, and the rate of increase is stronger for more market-oriented activities (see Figure 4). Whereas overall industry R&D funding grew at a compound annual rate of 5.7 percent from 1953 to 1982, the comparable figures for industry-funded basic research, applied research, and development are 4.2 percent, 6.3 percent, and 5.9 percent, respectively. Real funding for R&D provided by the federal government, on the other hand, has been characterized by relatively sharp variations (see Figure 5).

Real federal expenditures for research, both applied and basic, have shown only a slight upward trend since the mid-1960s after rapid increases in earlier years. Real federal research funding increased 10.9 percent annually from 1953 to 1965 and only 1 percent per year from 1965 to 1982. Government-funded development activities, on the other hand, have been highly unstable in real terms, exhibiting no discernible trend since 1960. Most federal development funding is devoted to defense. Volatility in the federal R&D budget, particularly in development, can be linked to the waxing and waning of major policy issues: the Sputnik challenge in the mid-1950s, which focused attention on science issues; the budgetary burdens of the war in Indochina and the Great Society in the 1960s, neither of which were defined in technological terms; and finally the energy crisis of the 1970s, which renewed interest in the social potential of R&D.

Performers of R&D

A different picture of R&D activities in the United States emerges from a consideration of R&D performers rather than the sources of R&D funding. To a great extent, this is because the federal government, which is the source of approximately 50 percent of total R&D funds, actually carries out a much smaller portion of R&D. Instead, its funds are dispersed among several performers, as is shown in Figure 6. In terms of performance, industry is far and away the dominant agent in the R&D process, accounting for over 70 percent of total R&D performed in the United States--a share that has remained highly stable throughout the postwar era.

Figures 7 through 10 indicate the structure of R&D activities by performer, broken down according to the standard categories of basic research, applied research, and development. It is only when overall expenditures are disaggregated in this way that the crucial role played by universities becomes evident. Whereas the contributions of the academic community are lost when funding aggregates are discussed, its predominance in research--and especially basic research--is evident when these categories are treated separately: the "nonprofit" category in Figures 6 through 10 primarily refers to academic institutions. By the same token, Figure 10 indicates the importance of industrial performers in the development area. The extent to which universities rely on federal monies for R&D is indicated in Figure 11, which describes the sources of university R&D funds. The government's role as the sponsor of university research may be particularly important, given the fact that the share of industry R&D funds devoted to basic research has been declining for the past 20 years--although it might also be the case that increased federal funding has encouraged industry to

Figure 6.
R & D by Performer, 1953-1982

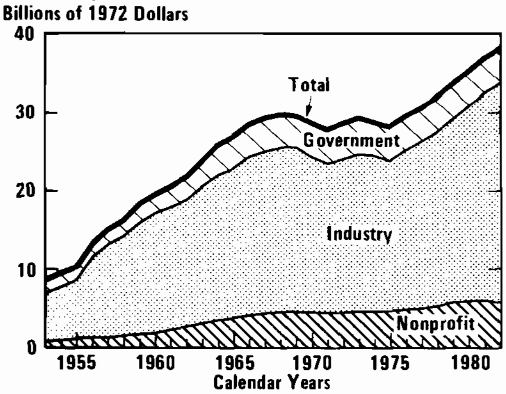


Figure 7.
Basic Research by Performer, 1953-1982

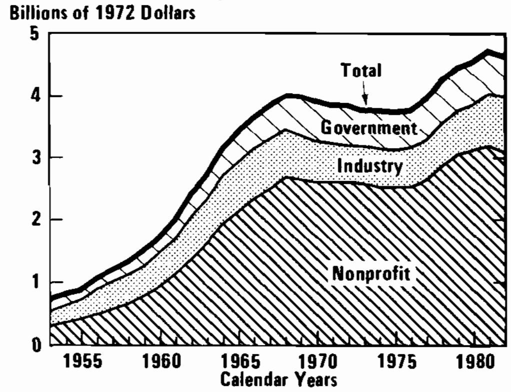


Figure 8.
Applied Research by Performer, 1953-1982

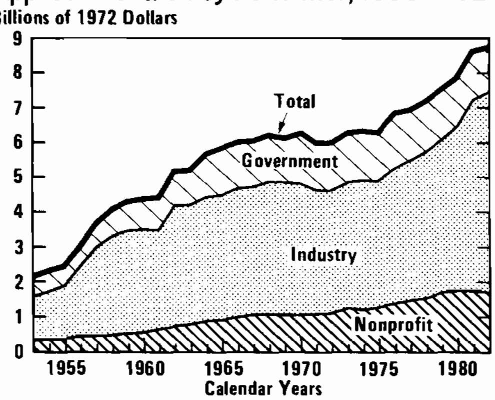


Figure 9.
Total Research by Performer, 1953-1982

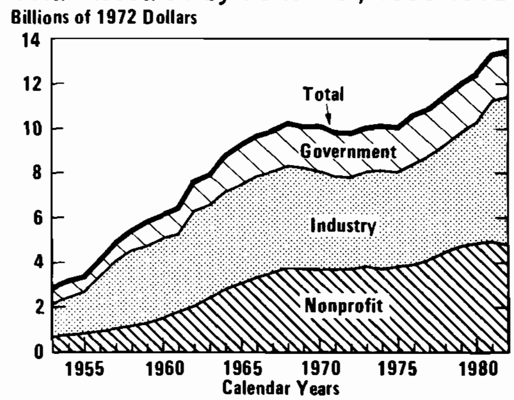
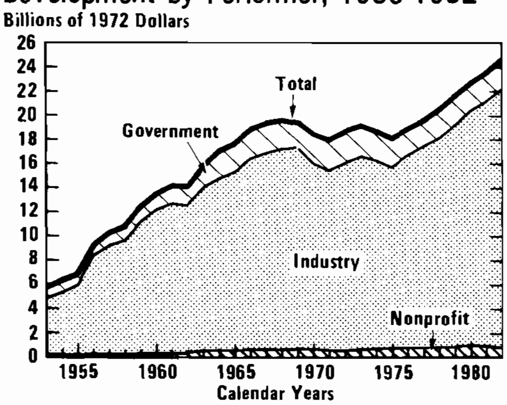
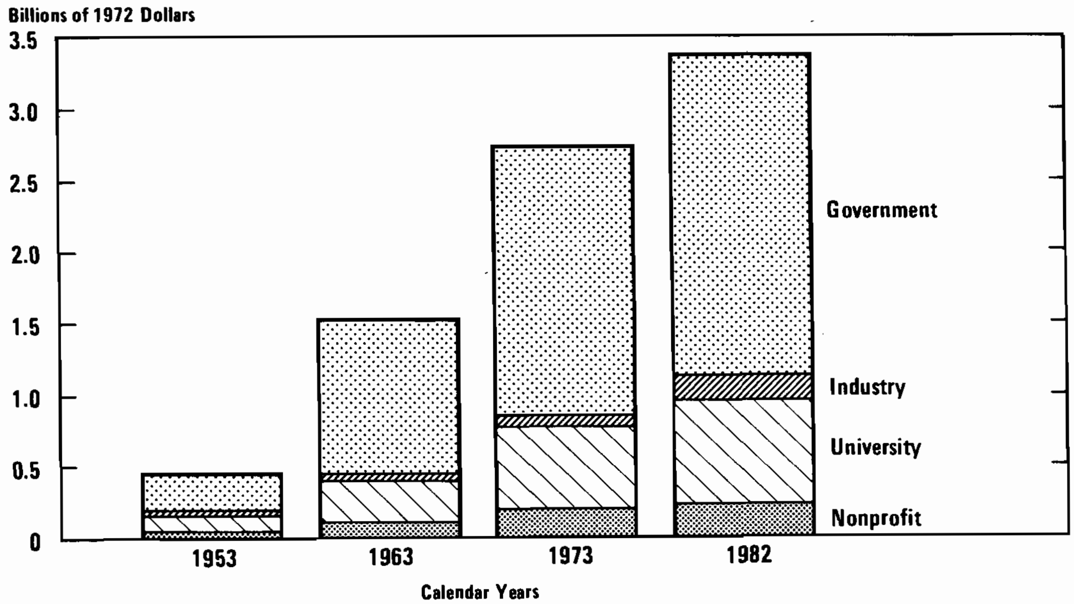


Figure 10.
Development by Performer, 1953-1982



SOURCE: National Science Foundation.

Figure 11.
Sources of University R&D Funds



SOURCE: National Science Foundation.

reduce its commitment to basic research. 10/ Recently, however, the private sector has been increasing its financial support for university-based research, particularly in microelectronics and biotechnology.

Past Trends in Federal R&D Funding

Recent shifts in the federal R&D budget will be discussed in Chapter IV, so that a briefer description of earlier trends will suffice at this point. On the most general level, Figure 12 shows how federal spending has been allocated among defense, civilian, and space-related functions. Through the 1950s, federal R&D spending was dominated by defense activities, which as late as 1960 claimed 80 percent of the government's

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10. For a discussion of basic research in industry, see E. Mansfield, "Basic Research and Productivity Increase in Manufacturing," American Economic Review, 70, 5, pp. 863-873 (1980).

Figure 12.
Federal R&D by Budget Function, 1953-1980

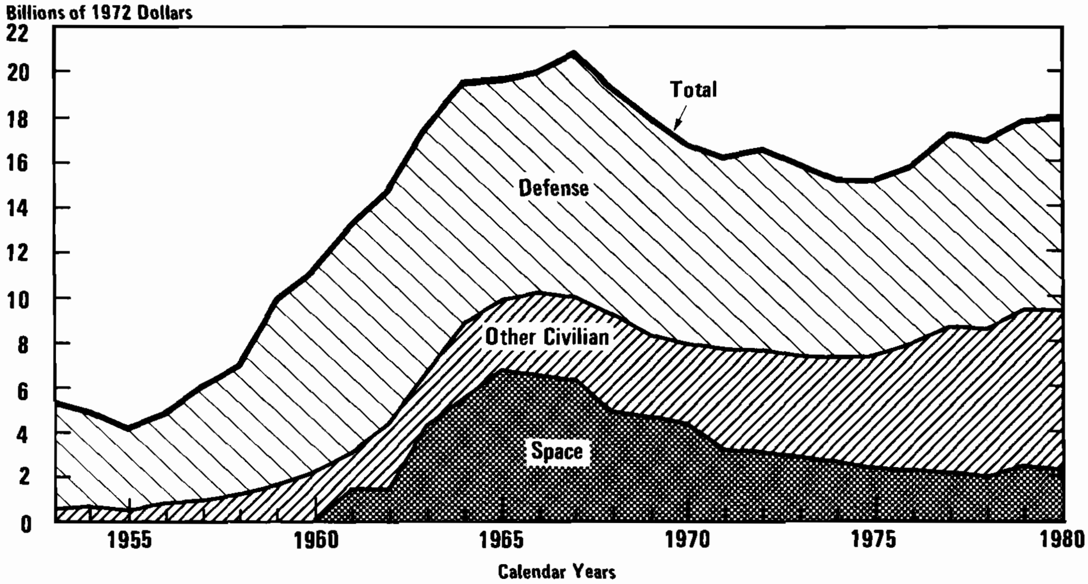
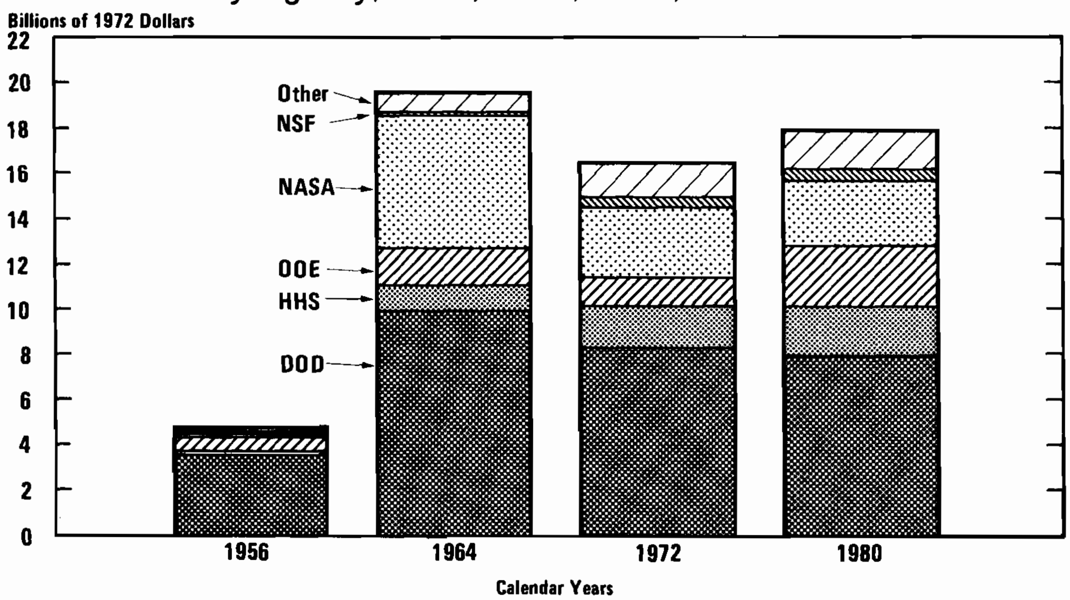


Figure 13.
Federal R&D by Agency, 1956, 1964, 1972, and 1980



SOURCE: National Science Foundation.

R&D budget. In the 1950s the federal government also assumed responsibility for funding civilian basic research, through the National Science Foundation (NSF) and the National Institutes of Health, but such expenditures were dwarfed by defense funding.

By the early 1960s, this pattern began to shift. First of all, funding for civilian (nonspace and nondefense) R&D began to increase at a fairly rapid rate (18 percent per year in real terms from 1961 to 1965), sustained first by relatively widespread increases (in areas such as medicine, agriculture, and energy) and eventually by the programs more specifically related to the energy crisis. This trend continued at least until the late 1970s.

The gradual increase in civilian R&D spending was accompanied by a more drastic decrease in the share of defense R&D in the federal total. The defense share had fallen to 50 percent by 1965, and it fluctuated around this level from then until the 1980s. To some extent, the drastic shift in the defense share from 1960 to 1965 reflected the emergence of the space program. During that period, the increasing commitment to space activities almost exactly offset the declining share of defense-related R&D funding. Since the mid-1960s, however, the share of space R&D in the federal R&D budget has fallen gradually, and this, rather than declines in defense per se, has offset the increased share of civilian R&D funding. These aggregate trends are also reflected in Figure 13, which describes several past federal R&D budgets in terms of agency funding.

It is worth reemphasizing that there is inevitably a strong subjective element in the functional allocation of R&D spending. For example, it appears that the defense share of federal R&D spending fell rapidly in the early 1960s, while space R&D increased dramatically. Yet one could argue that the space program has some military significance, an argument that is becoming more convincing as the military use of space becomes a more transparent policy objective. Another example of the subjective element in these allocations concerns the treatment of basic research, which is supposed to be divorced from practical applications. On these grounds, a purist could argue that any effort to allocate basic research spending along functional lines is inherently contradictory. Such allocation assumes that the function of research is determined by the departmental source of funds. If the Department of Defense funds advanced physics research, this is characterized as defense-related, while similar projects might be termed civilian if funded by the Department of Energy. On a more practical level, however, the definition of basic research often fails to correspond to the reality, where even very fundamental scientific work is mission-oriented in a broad sense.

CHAPTER III. R&D AND ECONOMIC PERFORMANCE

The belief that increased government support for R&D will improve the economy's performance is based on several assumptions: first, innovation and economic performance are closely linked; second, R&D causes superior innovative performance; and third, the government can influence both the level and efficiency of commercially oriented R&D. This chapter addresses some of the questions that underlie these assumptions:

- What evidence is there that the rate of return on R&D investments is high enough to justify greater governmental support?
- What is the current sectoral pattern of R&D activity in the economy, and how is that pattern related to the performance of different sectors?
- What effect does current government policy have on the technological performance of different sectors?
- How do R&D activities in the United States compare with international norms?

This chapter begins with a review of the evidence linking the return to R&D expenditures with performance in various industries and the economy as a whole. The major part of this chapter concentrates on R&D's effects on one measure of performance, namely, international competitiveness. The chapter concludes with a comparison of U.S. and foreign R&D spending.

MEASURING THE RETURN TO R&D

If R&D is viewed as an investment, it should have a measurable rate of return that can be evaluated against other investments, for example, capital equipment or education. An extensive literature has been devoted to measuring the rate of return to R&D, particularly as it relates to calculated rates of productivity growth. These studies are based on some form of "production function," that is, a mathematical formula that relates economic output to the inputs to the production process, such as labor, capital, and R&D expenditures. Production functions can be used to calculate the contribution of different inputs to measured increases in output, and this contribution can be interpreted to define a rate of return for the corresponding input, such as R&D.

Table 1 describes the results of several studies that have sought to estimate the rate of return to R&D. In addition, the table presents information on the scope of these studies and the types of assumptions they make. Although these estimates vary widely, they all suggest that the rate of return on R&D is higher than the return to most other investments. Several studies also argue that reduced R&D spending was partially responsible for declining rates of productivity growth in the U.S. economy during the 1970s--although estimates of the magnitude of this responsibility vary widely. 1/ The results of the studies support the view that R&D is a remunerative investment: the benefits of research and development in terms of increased output exceed the costs of carrying out the R&D. Moreover, these studies may understate the rate of return to R&D since they do not capture the effects of quality improvements.

Despite the simplified assumptions needed to execute these studies, their results strengthen the case for federal R&D support. If the measured rate of return to R&D exceeds the average return to other investments, this suggests that the private sector underinvests in R&D because of barriers, such as nonappropriability. In these circumstances, federal funding of R&D can help to improve economic output and overall economic well-being.

Although increasingly sophisticated studies have been devoted to estimating the rate of return to R&D, the potential complications associated with necessarily simplified assumptions remain unavoidable. While the studies produce uniformly high estimates of the rate of return to R&D, most do not clearly demonstrate the economic benefits of government-funded R&D. 2/ Several factors could contribute to this analytic problem,

1. See Congressional Budget Office, The Productivity Problem: Alternatives for Action (January 1981).

2. References to this issue can be found in Z. Griliches, "Returns to Research and Development Expenditures in the Private Sector" in Kendrick and Vaccara, eds., New Developments in Productivity Measurement and Analysis, (Chicago: University of Chicago Press, National Bureau of Economic Research, 1980); N. Terleckyj, "Direct and Indirect Effects of Industrial Research and Development in the Productivity Growth of Industries," ibid.; W. Leonard, "Research and Development in Industrial Growth," Journal of Political Economy (February 1979); and M. Ishaq Nadiri, "Contributions and Determinants of Research and Development Expenditures in the U.S. Manufacturing Industries" in G.M. von Furstenberg, ed., Capital, Efficiency and Growth (Cambridge, Massachusetts: Ballinger, 1980).

TABLE 1. ESTIMATED RETURNS TO R&D EXPENDITURES

Author	Rate of Return to R&D Expenditures (In percents)	Object of Study	Years Covered	Notes
Mansfield a/	40-60	Petroleum Industry	1945-1958	Technology change assumed to be embodied in capital
	30	Chemical Industry		
	7	Chemical Industry		Technology change assumed to be organizational
Minasian b/	54	Chemical Industry	1938-1957	Gross social return
Fellner c/	31	Macroeconomy	1953-1966	High-range estimates of R&D costs
	55	Macroeconomy		Low-range estimates of R&D costs
Griliches d/	93	Chemical & Petroleum	1957-1965	Based on confidential census data
	25	Metals & Machinery		
	2	Electrical Equipment		
	23	Motor vehicles		
	5	Aircraft		
	17	Manufacturing average		
Terleckyj e/	29	Macroeconomy	1948-1966	Return to firm-financed R&D
	78	Macroeconomy		Return to R&D embodied in purchased inputs
Scherer f/	70-104	Macroeconomy	1973-1978	Internal process R&D and input-embodied R&D
Nadiri g/	20	All Manufacturing	1958-1975	
	12	Durables		
	86	Nondurables		

(Continued)

TABLE 1. (Continued)

Author	Rate of Return to R&D Expenditures (In percents)	Object of Study	Years Covered	Notes
Link h/	51 34 21	Chemical Industry Machinery Industry Petroleum Industry	1975-1979	Rate of return increased by roughly 15 to 85 percent if environmentally mandated R&D is excluded

a. Edwin Mansfield, "Rates of Return from Industrial Research and Development," American Economic Review, vol. 55(2) (May 1965), pp. 310-322.

b. Jora Minasian, "Research and Development, Production Functions, and Rates of Return," American Economic Review, vol. 59(2) (May 1969), pp. 80-85.

c. William Fellner, "Trends in the Activities Generating Technological Progress," American Economic Review, vol. 60(1) (March 1970), pp. 1-29.

d. Zvi Griliches, "Returns to Research and Development Expenditures in the Private Sector" in John W. Kendrick and Beatrice N. Vaccara, eds., New Developments in Productivity, Measurement and Analysis, (Chicago: University of Chicago Press, 1980), pp. 419-454.

e. Nestor Terleckyj, Effects of R and D on the Productivity Growth of Industries: An Exploratory Study (Washington, D. C.: National Planning Association, 1974).

f. F.M. Scherer, "Inter-industry Technology Flows and Productivity Growth," Review of Economics and Statistics, vol. 64 (November 1982), pp. 627-34.

g. M. Ishaq Nadiri, "Contributions and Determinants of Research and Development Expenditures in the U.S. Manufacturing Industries" in G. von Furstenberg, ed., Capital, Efficiency and Growth (Cambridge, Massachusetts: Ballinger, 1980), pp. 361-92.

h. A.N. Link, "Productivity Growth, Environmental Regulations and the Composition of R&D," The Bell Journal of Economics, vol. 13 (Autumn 1982), pp. 166-69.

including the difficulty in measuring the return to R&D in defense and similar sectors, government spending, or the long-term and indirect effects of the greater efficiency of the private sector in generating economic benefits from R&D. 3/ While measuring the rate of return to federal support of R&D has proven a difficult task, there are still strong theoretical justifications for a substantial federal role. Furthermore, industry studies provide many examples of cases in which government funding has improved the technological performance of specific industries (for example, aviation and semiconductors), although counterexamples (such as housing) can be found as well. 4/

R&D AND ECONOMIC COMPETITIVENESS

An industry's performance can be measured by several criteria: productivity growth, profitability, sales growth, and so on. This section focuses on international competitiveness, both because it is relatively easy to measure and because it is a major policy concern. Industries that are R&D intensive are generally effective competitors on the world market. Moreover, government funding also seems to be closely linked with competitiveness, suggesting that the sectoral pattern of federal R&D support represents a tacit industrial policy with significant implications for sectoral performance. This implies that the pattern of federal R&D support may partially determine which U.S. industries do and which do not contribute to the balance of payments. These relationships seem to hold true for both direct R&D intensity, which concerns R&D spending within an industry, and for total R&D intensity, which includes the R&D embodied in purchased inputs. When input-output relationships are used to calculate total R&D intensity, it becomes clear that many basic industries are embedded in a network of less R&D-intensive industries, so that their own efforts to increase R&D are weighed down by the fact that they rely on technologically unsophisticated inputs from related industries. Although the opposite condition benefits firms in high-tech industries, the international competitiveness of some U.S. high-tech industries also has been declining.

This suggests that a general technological weakness, in addition to the transition from low-tech to high-tech sectors, is at least partially responsi-

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3. See P. Kochanowski and H. Hertzfeld, "Often Overlooked Factors in Measuring the Rate of Return to Government R&D Expenditures," Policy Analysis (1981).

4. See R. R. Nelson, ed., Government and Technical Progress: A Cross-Industry Analysis (New York: Pergamon, 1982).

39-373 O - 84 - 4

ble for current U.S. industrial problems. One reason for this might be the fact that U.S. industries are not aggressive adopters of foreign technologies--a problem that resides less in R&D funding than in the rate at which innovations are diffused through the economy. In addition, some foreign countries (for example, Japan and West Germany) devote a greater share of their GNP to civilian R&D rather than defense-related R&D, a characteristic that probably improves their competitiveness. Some reorientation of federal R&D support toward civilian activities, therefore, might improve the competitiveness of key sectors of the American economy.

While international competitiveness is an important objective of government policy, it should be pointed out that not all U.S. industries can be net exporters. Exports must be balanced by some outflow of dollars, either as payment for imports or as foreign investments. Export competitiveness in some industries is, therefore, likely to be offset by a lack of competitiveness in others. Rather than an impossible export surplus in all industries, the relevant policy issue in terms of American competitiveness is the mix of exports and imports: is the current structure of U.S. trade acceptable in terms of other policy goals (employment, regional performance, national defense, and so forth)? If not, could changes in government policy alter the pattern of U.S. trade in positive ways? The current pattern of government R&D support by industry may reflect policies that could be changed to affect the relative competitiveness of different sectors of the U.S. economy. Even so, feasible shifts in the level and mix of federal R&D subsidies could still be more than offset by the more powerful forces that affect trade flows, such as exchange rates and trade barriers.

International Competitiveness and R&D Intensity: The Basic Evidence

Table 2 presents data on the intensity of R&D funding in various industries, shown as a percent of net sales. 5/ R&D intensity is widely dispersed. As expected, industries commonly thought of as high-tech spend a large share of net revenues on R&D; this is true of aircraft and missiles, scientific instruments, chemicals, and electrical instruments. By the same token, supposedly low-tech industries devote a relatively paltry share of net revenues to R&D; this is the case for textiles, primary metals (especially iron and steel), and fabricated metals. In general, consumer-goods industries and industries close to raw materials processing tend to be characterized by low R&D intensity.

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5. The data in Table 2 are derived from industry responses to surveys conducted by the National Science Foundation, which are reported periodically in the series of NSF reports, "Research and Development in Industry."

TABLE 2. R&D INTENSITY IN SELECTED INDUSTRIES FOR 1960, 1970, AND 1981
(Total R&D funding as a percent of net sales)

Industry	SIC Code a/	R&D Intensity 1960	1970	1981
Aircraft and Parts	372,376	22.5	16.2 b/	15.3 b/
Scientific Measuring Instruments	381-2	8.6	3.5	9.2
Other Instruments	383-7	5.3	6.6	7.8
Electrical Equipment	36	11.2	7.3	6.8
Communication equipment and components	366-7, 48	13.1	8.2	8.9 b/
Machinery	35	4.7	4.0	5.2
Office and computing machinery	357	c/	c/	11.7
Other machinery	351-6, 358-9	c/	c/	2.5
Motor Vehicles and Other Transportation Equipment	371, 373-5, 379	3.0	3.5	4.1 b/
Motor vehicles	371	c/	c/	4.5
Other transportation equipment	373-5, 379	c/	c/	0.5
Chemicals	28	4.5	3.9	3.8
Industrial chemicals	281-2	5.7	4.2	3.5
Drugs	283	4.8	6.7	6.4
Other chemicals	284-9	2.2	1.8	2.1
Rubber Products	30	2.0	2.3	2.5
Fabricated Metal Products	34	1.3	1.2	1.4
Nonferrous metals	333-6	1.0	1.0	1.2
Paper and Allied Products	26	0.7	0.9	1.1
Lumber, Wood Products, Furniture	24, 25	0.6	0.8	0.9
Ferrous Metals	331-2, 3398-9	0.6	0.7	0.8
Petroleum Refining	29	1.0	1.0	0.7
Textiles and Apparel	22, 23	0.6	0.5	0.4

SOURCE: National Science Foundation.

a. SIC = Standard Industrial Classification.

b. Estimated from NSF data.

c. Not available.

Using these same data, R&D intensity can be related to industrial performance, which can be measured in several ways: profitability, growth of sales, trade balance, and so on. The measure used here concerns international competitiveness and is based on the methodology of D. B. Keesing, who linked an industry's R&D intensity (R&D funding as a percent of net sales) in 1960 to the U.S. share of developed-country exports for the industry's product in 1962. 6/ The two-year lag, although arbitrary, is used to reflect the fact that R&D investments have delayed effects. Keesing found a very close relationship (linear correlation coefficient of 0.90 and rank correlation coefficient of 0.92) between R&D spending and international competitiveness. Moreover, he found that the linear correlation between international competitiveness and government R&D funding was higher than the linear correlation between international competitiveness and private R&D spending. This difference is probably caused by the interaction of two factors: government spending is highly skewed toward technology-intensive industries, and the government has provided most of the funding for several key industries that are highly successful international competitors. Insofar as government R&D subsidies increase the export performance of some sectors, nonsubsidized sectors inevitably suffer some loss of international competitiveness.

Keesing's analysis was based on a very simple model, and its assumptions may be somewhat unrealistic. Most important, his measure of R&D intensity is industry-specific rather than product-specific, so that it fails to take account of product-line diversification by firms. In addition, his measure of R&D intensity does not include the R&D embodied in purchased inputs. Nevertheless, more sophisticated investigations of this issue, although typically focused on the performance of high-tech industries, have tended to support Keesing's conclusions. 7/ Table 3 presents more recent data showing the relationships between international competitiveness, defined by the U.S. share of developed-country exports, and R&D intensity, defined as R&D expenditures as a percent of value added. The major difference between CBO's and Keesing's methodology is that CBO's data are

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6. Donald B. Keesing, "The Impact of Research and Development on United States Trade," Journal of Political Economy, vol. 75, no. 1 (January/February 1967), pp. 38-48.

7. See for example Michael Boretsky, "Concerns About the Present American Position in International Trade," Technology and International Trade, (Washington, D.C.: National Academy of Sciences, 1971); and R. K. Kelly, The Impact of Technology Innovation on International Trade Patterns, (Washington, D.C.: Department of Commerce, 1977).

TABLE 3. R&D INTENSITY AND INTERNATIONAL COMPETITIVENESS FOR SELECTED YEARS (Total R&D funding as a percent of valued added)

NSF Product Class	Average R&D Intensity, 1968-1970 a/	U.S. Export Share, 1971 b/	Average R&D Intensity 1977-1979 a/	U.S. Export Share, 1980 b/
Electronics and Communications Equipment	16.2	36.1	18.6	35.4
Aircraft and Parts	21.0	64.7	17.5	53.0
Office and Computing Equipment	18.9	33.2	14.9	32.4
Engines and Turbines	10.2	25.2	9.9	28.2
Drugs and Medicines	8.9	13.9	9.4	15.6
Plastics	10.4	11.4	9.0	14.2
Professional and Scientific Instruments	9.6	21.7	6.9	28.0
Agricultural Chemicals	11.2	18.6	6.2	29.7
Industrial Chemicals	4.6	20.7	4.1	12.7
Farm Equipment	0.8	27.8	4.1	27.1
Construction Equipment	3.4	25.5	3.6	14.7
Motor Vehicles	6.0	16.5	3.4 c/	6.8
Other Electronics	3.7	14.6	3.2	18.7
Electrical Transmission and Distribution Equipment	3.4	10.8	3.1	8.2
Fabricated Metals	1.9	13.5	2.5	12.9
Metalworking Equipment	3.2	16.1	2.2	12.8
Other Transportation Equipment	2.5	5.4	2.1	16.5
Rubber Products, etc.	2.2	11.5	1.8	10.1
Nonferrous Metals	1.5	10.1	1.3	14.0
Stone, Clay, and Glass	1.4	10.1	1.0	8.0
Ferrous Metals	1.0	5.6	0.6	4.7
Textile Mill Products	0.6	5.7	0.5	1.2
Linear Correlation	.78		.83	

SOURCE: Product-line R&D data from NSF's Industry Studies Group, Division of Science Resource Studies. Export data from OECD Trade-by-Commodities reports.

a. Average R&D expenditures as a percent of value added.
b. U.S. share of total developed-country exports.
c. CBO estimate.

product-specific while Keesing's are industry-specific. The methodology used in constructing Table 3 is described in Appendix A.

These data show a high correlation between R&D intensity and international competitiveness, especially when placed in the context of the variety of factors that affect trade flows. Table 3 suggests that a strong R&D effort is characteristic of American industries that are effective international competitors, while industries with severe competitive problems invest significantly less in R&D. Moreover, other empirical studies of this subject, using alternative measures of competitiveness or R&D intensity, produce similar results.

These results are subject to differing interpretations, however. One could argue that low-tech sectors use production processes that have relatively meager prospects for significant technological progress. According to this view, high R&D intensity is less a cause than a characteristic of technological progressiveness, so that government programs to boost the R&D intensity of sectors that are inherently low-tech would be a wasted effort. The principal alternative to this view is that greater R&D intensity could revitalize low-tech sectors, making this both a realizable and a worthwhile policy goal.

The truth probably lies somewhere between these two extremes. But Keesing's argument that government R&D spending by industry is closely correlated with the U.S. share of world exports suggests that government R&D support does improve an industry's international performance. Although not enough information is available to test this hypothesis by using the product-specific data presented in Table 3, Keesing's results are confirmed if his industry-specific methodology is applied to the period since 1960. Moreover, some studies show that federal funding may play a key role in eliciting complementary funding by private firms and in increasing the return to privately funded R&D. 8/ If this is the case, the government may actively shape the technological performance of different industries, at least in part. Low-tech sectors might, therefore, benefit from increased federal support in developing their technology base.

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8. See Edwin Mansfield, Studies of Federally Funded Research and Development, Market Structure and International Technology Transfer: A Final Report (Washington, D.C.: National Science Foundation, 1983); and D. M. Levy and N. E. Terleckyj, "Effects of Government R&D on Private R&D Investment and Productivity: a Macroeconomic Analysis," The Bell Journal of Economics, vol. 14, no. 2 (Autumn 1983).

Table 4 shows how drastically federal R&D funding is skewed among industries. The government provides almost half of the R&D funding for the aircraft industry and only 8 percent of the R&D expenditures of the fabricated metals industry. Figure 14 illustrates this point from a somewhat different perspective, showing how federal R&D funds are distributed among industries. Aerospace (which includes missiles as well as aircraft) receives over half of this total, while electrical equipment (primarily communications) and machinery (primarily computers) account for almost 30 percent. The residual--less than 20 percent in 1981--is distributed among all other industries, from transportation equipment to steel to textiles. Moreover, a relatively small number of large firms, particularly in defense industries, receive the bulk of the federal R&D resources that are channelled to the private sector. Discrepancies of the magnitude described in Table 4 and Figure 14 suggest the extent to which a de facto industrial policy--that is, government programs that benefit some sectors and not others--is embedded in the pattern of federal R&D funding, even though this pattern may be dictated by other concerns, such as national security.

R&D Intensity and the Balance of High-Tech Trade

The results discussed above are based on the intensity of R&D funding within an industry, a measure that is somewhat incomplete. Besides the direct R&D intensity measured by the share of an industry's revenues devoted to R&D, a more comprehensive measure must include the R&D embodied in the inputs used by an industry. Some industries--ferrous metals, lumber and wood products, textiles, for example--perform very little R&D on their own. Nevertheless, such industries can benefit significantly from the R&D carried out by equipment suppliers, whose new product innovations serve as process innovations for industries that purchase such equipment. An industry that relies heavily on innovations generated by other sectors of the economy can be technologically progressive regardless of its internal level of R&D funding. This section applies the concept of total R&D intensity, which relates direct and indirect R&D expenditures to total shipments, to supplement the overall analysis of international competitiveness, to assess the competitiveness of technology-intensive sectors and to suggest some reservations about industry-specific increases in R&D funding.

The simplest means of calculating total R&D intensity is to apply input-output analysis, weighting an industry's inputs by the direct R&D intensity of the industries that produce the inputs. The U.S. Department of Commerce has used this approach to develop a comprehensive measure of R&D intensity, and the results of its study are shown in Table 5, which

TABLE 4. R&D INTENSITY FOR CORPORATE AND GOVERNMENT FUNDING BY INDUSTRY FOR 1960, 1970, AND 1981 (R&D funding by source as a percent of net sales)

Industry	1960		1970		1981	
	Corporate	Government	Corporate	Government	Corporate	Government
Aircraft and Parts a/	b/	b/	10.3	12.4	9.5	8.0
Scientific Measuring Equipment	4.1	7.7	2.9	0.6	7.0	2.2
Drugs	4.7	0.1	b/	b/	b/	b/
Machinery	2.7	1.6	3.4	0.6	4.6	0.6
Office and computing machinery	b/	b/	b/	b/	10.1	1.6
Other machinery	b/	b/	b/	b/	2.3	0.2
Chemicals	3.7	0.8	3.5	0.4	3.5	0.3
Electrical Equipment	3.7	7.2	3.4	3.9	4.2	2.6
Rubber Products	1.4	0.7	1.7	0.6	b/	b/
Motor Vehicles and Other Transportation Equipment	2.4	0.7	2.8	0.7	3.6	0.5
Other Instruments	4.4	2.1	4.7	1.9	6.7	1.1
Petroleum Refining	1.0	0.1	0.9	0.1	0.6	0.1
Fabricated Metal Products	1.0	0.5	1.1	0.1	1.3	0.1
Nonferrous Metals	0.9	0.2	0.9	0.1	0.7	0.5
Paper, etc.	0.7	---	b/	b/	b/	b/
Lumber, etc.	0.5	0.1	0.8	---	0.9	---
Textiles and Apparel	0.4	0.2	b/	b/	b/	b/
Ferrous Metals	0.6	---	0.7	---	0.6	0.2

SOURCE: National Science Foundation.

a. CBO estimate from NSF data on product field.
b. Not available.

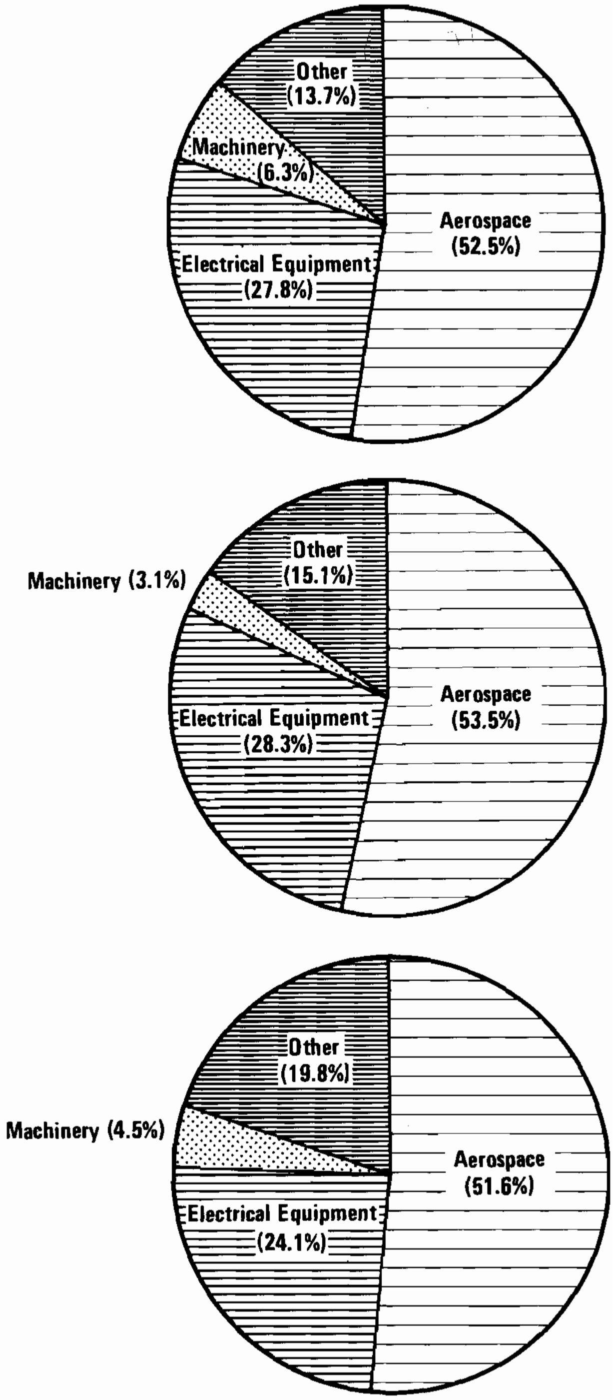
Figure 14.

Federal R&D Funding by Industry for 1957, 1969, and 1981

1957

1969

1981



SOURCE: National Science Foundation.

TABLE 5. TOTAL AND DIRECT R&D INTENSITY FOR THE 1977-1979 PERIOD

Industry	Total R&D Intensity a/	Direct R&D Intensity b/	Ranking by R&D Intensity Total	Direct
Guided Missiles and Spacecraft	63.9	48.8	1	1
Communications Equipment and Electronic Components	16.0	12.0	2	3
Aircraft and Parts	15.4	11.8	3	4
Office Computing and Accounting Machinery	13.6	09.5	4	5
Ordnance and Accessories	13.6	12.2	5	2
Drugs and Medicines	08.4	07.1	6	6
Industrial Inorganic Chemicals	08.2	05.1	7	7
Professional and Scientific Instruments	05.7	04.3	8	8
Engines, Turbines, and Parts	05.5	04.1	9	9
Plastic Materials, etc.	05.4	03.9	10	10
Agricultural Chemicals	04.2	02.5	11	12
Motor Vehicles and Equipment	04.1	02.2	12	14
Electrical Transmission and Distribution Equipment	03.6	02.3	13	13
Apparata	03.5	02.6	14	11
Farm Machinery and Equipment	03.2	02.0	15	15
Rubber and Miscellaneous Plastic Products	02.7	01.0	16	23

(Continued)

TABLE 5. (Continued)

Industry	Total R&D Intensity a/	Direct R&D Intensity b/	Ranking by R&D Intensity Total	Ranking by R&D Intensity Direct
Other Electrical Equipment and Supplies	02.6	01.5	17	16
Fabricated Metal Products	02.6	01.3	18	19
Other Transportation Equipment	02.4	01.1	19	22
Construction, Mining, Material Handling Equipment	02.4	01.5	20	18
Textile Mill Products	02.2	00.3	21	29
Metalworking Machinery	02.1	01.5	22	17
Other Mechanical, Excluding Electrical	02.0	01.2	23	20
Stone, Clay, and Glass	01.6	00.6	24	25
All Other Manufacturing	01.6	01.1	25	21
Other Chemicals	01.4	00.9	26	24
Nonferrous Metals and Products	01.3	00.5	27	27
Food and Kindred Products	00.9	00.2	28	30
Petroleum Refining Products	00.8	00.5	29	26
Ferrous Metals and Products	00.5	00.3	30	28

SOURCE: Lester A. Davis, "New Definitions of 'High-Tech' Reveals That U.S. Competitiveness Has Been Declining," Business America, October 18, 1982, p. 20.

a. Direct expenditures for R&D plus R&D expenditures embodied in purchased inputs as a percent of total sales.

b. R&D expenditures by the direct producer as a percent of total sales.

describes industries' total and direct R&D intensity and ranks them accordingly.[9]

Table 5 shows, first of all, that the ranking of industries by direct R&D intensity is not greatly affected by the inclusion of indirect intensity data. In other words, industries that perform substantial amounts of R&D also tend to have technologically sophisticated suppliers. Only a limited number of industries undergo a shift of more than two places: ordnance (+3), electrical industrial apparata (-3), rubber and miscellaneous plastic products (+7), the residual category for transportation equipment, excluding aircraft and motor vehicles (+3), textile mill products (+8), metalworking machinery (-5), other nonelectrical machinery (-3), petroleum refining (-3), and "all other manufacturing" (-4).

Second, Table 5 shows that nine of the ten industries that rank lower by total R&D intensity than by direct R&D intensity can be described as traditional manufacturing industries--the exception being the still highly ranked ordnance industry. This suggests that the performance of traditional manufacturing firms has been undermined not only by their own lack of commitment to R&D but also by the lackluster technological performance of their suppliers (or alternatively, by the fact that traditional manufacturing firms have not sought to adopt more high-tech inputs). These data imply that even a strong commitment to R&D by a traditional manufacturing firm may be weighed down or even offset by the low R&D intensity of the industries on which the firm must rely for inputs.

Third, Table 5 confirms the point that industries with the highest total R&D intensity are those with a high degree of government funding. Measured by total R&D intensity, all of the top five industries receive significant government support, especially from the Department of Defense. This suggests that the sectors that serve the defense establishment benefit from the high levels of R&D carried out in the sector as a whole, supplementing their own R&D activities. The intersectoral effects of R&D expenditures, through the indirect component of R&D intensity, thus seem to foster a split in the U.S. economy between high-tech sectors, generally characterized by a substantial degree of government R&D support, and more traditional manufacturing industries, which are gradually sinking into a low-tech status.

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9. Lester A. Davis, "New Definitions of 'High-Tech' Reveals That U.S. Competitiveness Has Been Declining," Business America, October 18, 1982, p. 20. See also F.M. Scherer, "Inter-industry Technology Flows in the United States," Research Policy, vol. 11, (August, 1982), pp. 227-245.

In terms of international competitiveness, using total R&D intensity as a measure does not significantly alter the conclusions that were suggested by using direct R&D intensity. The linear correlation between total R&D intensity in 1977-1979 and the U.S. share of world exports in 1980 is .76, compared with .83 for direct R&D intensity.

More interestingly, however, investigations based on total R&D intensity indicate that, although the evolving pattern of U.S. trade is based on a U.S. comparative advantage in high-tech products, there may be competitive problems in both high-tech and low-tech sectors. 10/ The boundary between high-tech and low-tech is inevitably somewhat arbitrary. The Commerce Department study that is the source for Table 5 suggests that the set of high-tech industries should be demarcated by a substantial increase in R&D intensity rather than by an arbitrary comparison with average intensity. On those grounds, "plastic materials, etc." is the last element in the high-tech set; its total R&D intensity is more than 25 percent greater than the next most R&D-intensive sector (agricultural chemicals)--a much greater difference than is found after this break. In the late 1970s, the ten industries above that line accounted for over 50 percent of the total R&D embodied in U.S. manufacturing, although their share of shipments value was only 13 percent.

Using this definition of high tech, Table 6 supports the view that U.S. competitiveness has been deteriorating in the high-tech sector. Imports of high-tech products (defined as above) have been increasing their share of the U.S. market over the past decade (from 8.3 percent in 1974 to 11.9 percent in 1981), which suggests that the extent to which such industries provide a net benefit to the U.S. balance of payments has declined. The export surplus in high-tech products--that is, the extent to which the value of exports exceeds the value of imports--has been declining as a share of high-tech exports over the past decade (falling from 55.8 percent in 1974 to 45 percent in 1981). This result implies that the more obvious competitive difficulties of low-tech sectors cannot be viewed as merely the adjustment costs of the transition from a low-tech to a high-tech economy. The deteriorating export competitiveness of high-tech sectors, which predates the post-1980 appreciation of the dollar, suggests general weaknesses in the technological performance of the U.S. economy, a problem that is likely to increase insofar as other countries target high-tech industries for development.

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10. For an alternative view, see R. Lawrence, "Is Trade Deindustrializing America? A Medium Term Perspective," The Brookings Panel on Economic Activity, (Washington, D.C.: The Brookings Institution), April 14 and 15, 1983.

TABLE 6. HIGH TECHNOLOGY SHARE OF U.S. MANUFACTURING SHIPMENTS AND EXPORTS, EXPORT SURPLUS SHARE OF EXPORTS, AND IMPORT SHARE OF APPARENT CONSUMPTION, 1974-1981 (In percents) a/

	High Technology Manufacturing				
	Share of Total Manufacturing			Export Surplus as a Share	Import Share of Apparent
Year	Shipments	Exports	Imports	of Exports	Consumption b/
1974	13.2	29.3	13.0	55.8	8.3
1975	12.5	28.3	14.0	59.6	8.0
1976	12.5	28.9	16.2	49.8	9.5
1977	12.4	29.3	15.8	45.7	9.5
1978	12.8	30.3	16.5	42.0	10.9
1979	13.3	30.0	16.3	47.7	10.5
1980	14.2	31.5	17.5	50.3	11.2
1981	13.9	32.2	18.8	45.0	11.9

SOURCE: Lester A. Davis, "New Definition of 'High-Tech' Reveals That U. S. Competitiveness in This Area Has Been Declining," Business America, October 18, 1982, p. 22.

a. Based on trade data reported on a Standard Industrial Classification basis rather than a Standard International Trade Classification basis.

b. Ratio of imports to shipments, less exports, plus imports.

U.S. R&D EXPENDITURES WITHIN AN INTERNATIONAL CONTEXT

It is difficult to assess the adequacy of the U.S. R&D effort, described in the preceding sections, without some standard by which this performance can be judged. Estimates of the rate of return to R&D and the R&D contribution to productivity growth provide a rough indication of whether R&D expenditures in the U.S. are optimal, but such estimates are either too crude or too dependent on restrictive assumptions to have much policy significance. Measures of international performance shed some light on the importance of R&D, but trade flows are affected by many other factors as well. International comparisons of R&D spending provide another means for evaluating the adequacy of the U.S. R&D effort. 11/

Figure 15 describes estimated R&D expenditures, in 1972 dollars, in France, Japan, the United Kingdom, the United States, and West Germany. As these data show, total R&D expenditures in the United States far exceed those in other countries. Care should be taken in reading too much into this fact, however, since it largely stems from the greater size of the U.S. economy. Moreover, absolute comparisons of this type are inevitably affected by exchange rate fluctuations as well as by the general caveats that relate to R&D statistics. Nevertheless, the data presented in this figure are still useful if one assumes that there are economies of scale in R&D at the national level. Given such an assumption, the greater size of the U.S. economy is irrelevant, so that higher absolute levels of R&D spending represent an advantage for the U.S. economy. At the same time, however, the discrepancy has narrowed during the postwar period, so that the U.S. share of all R&D expenditures by these countries has fallen from 82 percent in 1965 to 65 percent in 1980.

Other measures may be more illuminating, however. International comparisons in the R&D area are most frequently based on the ratio of R&D expenditures to GNP, a measure of R&D intensity. This ratio describes the share of aggregate net income devoted to R&D, discounting the effect of differences in the size of national economies. Figure 16 shows the percentage share of R&D expenditures in the GNP of the same five countries portrayed in Figure 15. A very different picture emerges. In particular, the U.S. advantage narrows greatly or even disappears. The data indicate that West Germany, the United Kingdom, and the United States have all committed about the same share (roughly 2.3 percent) of GNP to research and development activities over the past decade. Japan and France have historically tended to spend a somewhat smaller share of GNP on R&D.

More importantly, the discrepancy between the United States and the other countries in terms of aggregate R&D intensity has narrowed considerably in the past two decades--although all of the countries concerned maintained a more or less flat trend in this ratio during the 1970s. For the postwar period as a whole, then, other countries have been catching up with

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11. The Congressional Research Service regularly reports on international trends in R&D spending. See, for example, W.C. Boesman, "U.S. Civilian and Defense Research and Development Funding: Some Trends and Comparisons with Selected Industrialized Nations" CRS Report No. 83-1835PR, August 29, 1983.

Figure 15.
Real R&D Funding in Selected Countries, 1961-1980

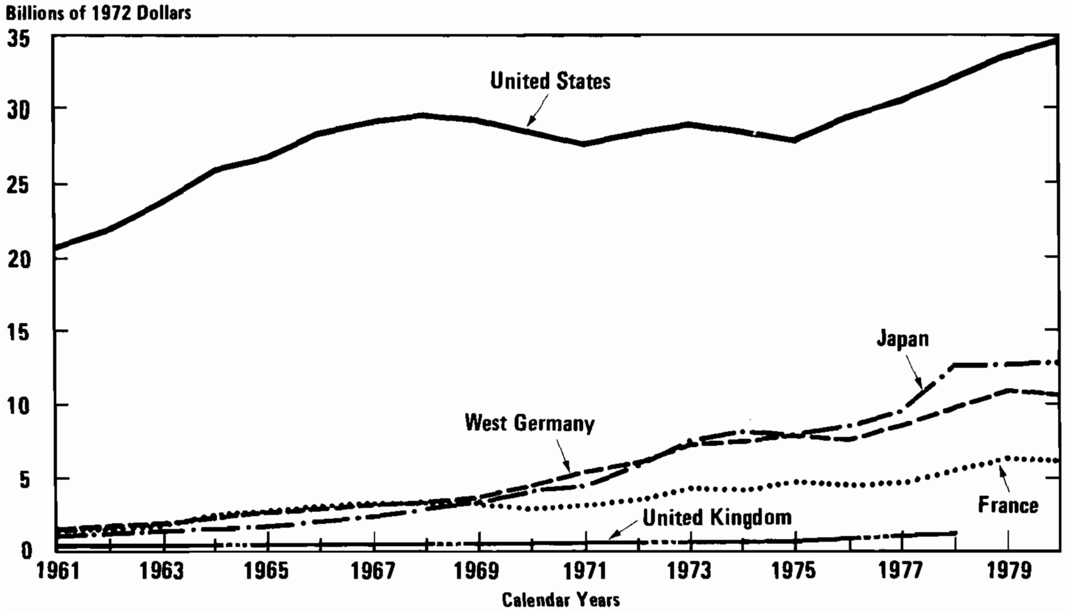
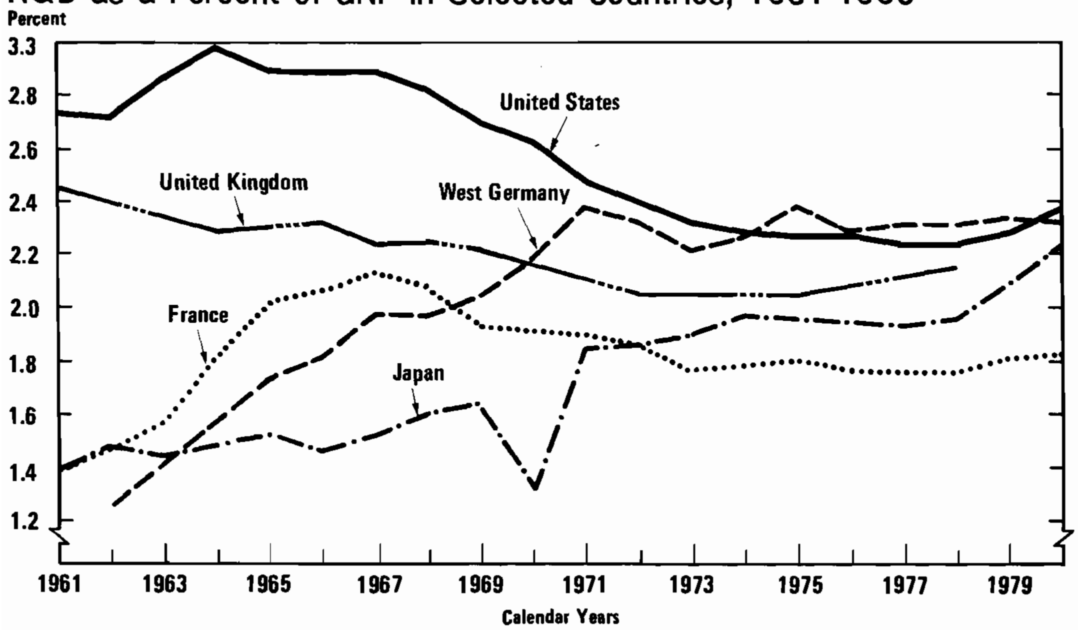


Figure 16.
R&D as a Percent of GNP in Selected Countries, 1961-1980



SOURCE: National Science Foundation.

the United States in terms of the portion of their resources they devote to R&D.

As is the case for absolute comparisons of R&D funding, however, one must be careful not to read too much into these trends. The relative standing of different countries in terms of this ratio is directly significant only to the extent that there are no macroeconomic economies of scale in R&D. If there were such economies of scale, a large economy, like that of the United States, could devote a lower share of its GNP to R&D than a smaller economy and still generate a greater stream of scientific and technical discoveries--both absolutely and relatively. Moreover, comparisons of this type are relevant only insofar as the price of R&D inputs relative to other goods is the same across countries. The share of GNP devoted to R&D may be most significant in terms of its status as a proxy for other variables--the general level of scientific and technical skills in the labor force, for instance. In and of itself, however, aggregate R&D intensity is only one of several measures that can be used to compare R&D performance internationally.

Further insight into the relative standing of the United States in terms of world standards for R&D can be gleaned from a disaggregation of the data presented in Figure 16. This country devotes a large portion of its R&D effort to noncivilian technologies, that is, to defense and space. Other countries place a greater emphasis on civilian technologies, as is shown in Figure 17, which describes the share of GNP devoted to civilian R&D. Here the U.S. performance has been near the bottom (among the countries compared) since at least the mid-1960s. This comparison is subject to the same caveats as the data presented in Figure 15: share-of-GNP rankings are valid only to the extent that aggregate economies of scale are limited. Nevertheless, several studies suggest that the benefits of noncivilian R&D for international competitiveness are limited. 12/ It may not be surprising, therefore, that Japan and West Germany, the two countries that have competed most successfully against U.S. manufacturing industries, both devote a significantly greater share of their GNP to civilian R&D.

Finally, it is worth recalling that technology and international competitiveness are linked most directly by the productive use of new products and processes, not by spending on R&D. A country may boost the impact of a given level of R&D funding by aggressively adopting the advances generated by foreign R&D. Thus, the pattern of international technology

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12. See, for example, William N. Leonard, "Research and Development in Industrial Growth," Journal of Political Economy, vol. 79, no. 2, (March-April, 1971), pp. 232-256.

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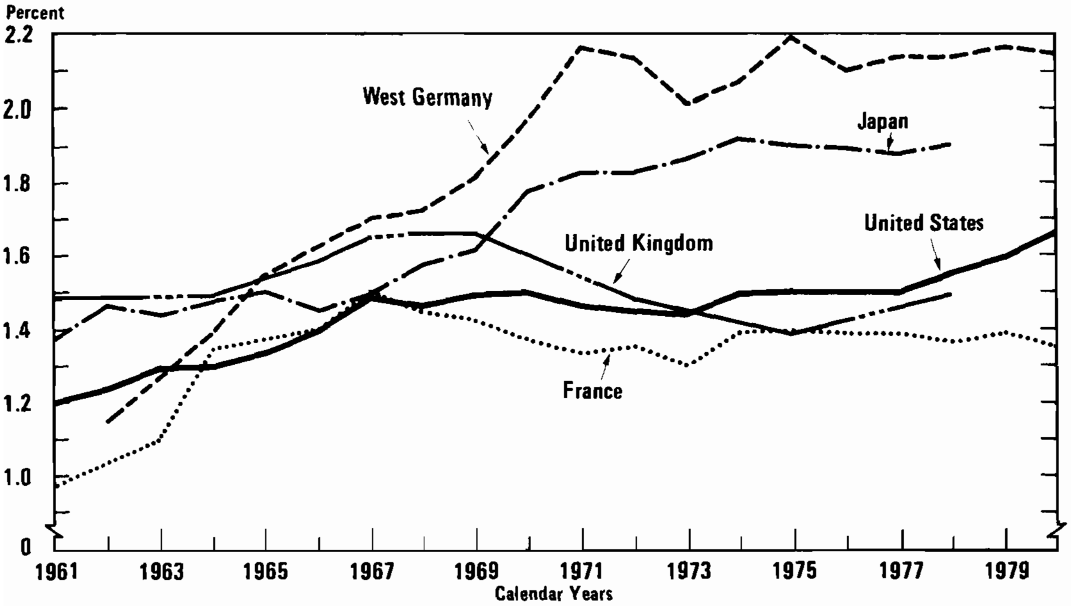
Figure 17.

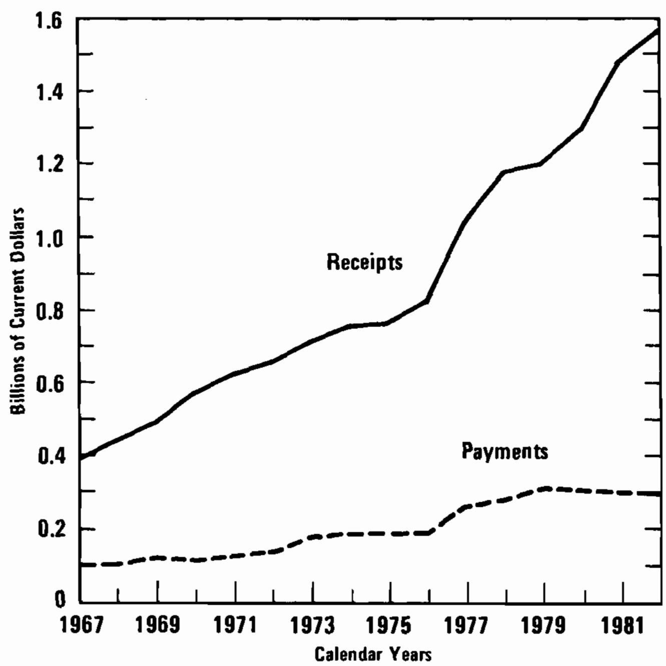
Civilian R&D as a Percent of GNP in Selected Countries, 1961-1980



SOURCE: National Science Foundation.

Figure 18.

U.S. Trade in Licenses and Fees, 1967-1982[a]



SOURCE: M.L. Kroner, "U.S. Investment Transactions in Royalties and Fees," U.S. Department of Commerce, *Survey of Current Business* (January, 1982) and *Survey of Current Business* (various issues).

[a] These data include only transactions with "unaffiliated" foreign parties—that is, payments that are not made to or received from foreign subsidiaries.

sales and purchases is relevant to an evaluation of a country's R&D effort, and this can be measured through trends in the royalties and fees paid for other countries' innovations. While such transactions do not completely describe technology transfers, they are revealing enough to provide some inferences about the comparative effectiveness of the U.S. R&D effort. 13/ Figure 18 shows the trend (in current dollars) in U.S. receipts and payments of fees and royalties with "unaffiliated" foreign parties--that is, payments that are not made to or received from foreign subsidiaries. As these data show, the U.S. retains a significant balance of payments surplus in such technology transfers.

A more interesting feature of these data, however, is the fact that U.S. payments to nonaffiliated firms for technologies developed abroad have failed to increase significantly over the past 20 years. Since the mid-1960s, the United States gradually has lost the technological preeminence it enjoyed in the first two decades after World War II. 14/ Moreover, the ongoing integration of the world economy has made it more important for U.S. firms to adopt capital- and energy-saving technologies, in addition to the labor-saving technologies that have characterized American manufacturing since the 19th century. Many other developed countries have traditionally suffered relative scarcities of capital, energy, or raw materials, so that they have sought technologies to conserve these inputs. The data in Figure 18 show no trend towards an accelerated purchase of such technologies by U.S. firms.

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13. The data presented in Figure 18 are merely indicative; a more comprehensive analysis of this issue would require some discussion of problems in the data and their applicability. See M. F. Teplin, "U.S. International Transactions in Royalties and Fees: Their Relationship to the Transfer of Technology," U.S. Department of Commerce, Survey of Current Business (December 1973); and M. L. Kroner, "U.S. International Transactions in Royalties and Fees, 1967-78," Survey of Current Business (January, 1980).

14. Measures of productivity improvement show faster growth outside the United States for most of the post-war period. In the steel industry, for instance, the Japanese required over 35 manhours to produce a ton of cold-rolled sheet in 1958, versus 11.6 in the U.S. By 1980, this had been reduced to 5.8 manhours for the Japanese and 7.2 for the U.S. See D.F. Barnett and L. Schorsch, Steel: Upheaval in a Basic Industry (Cambridge: Ballinger, 1983), p. 119.

Insofar as the United States has failed to boost its imports of technology, its technological base has been largely defined by the R&D undertaken domestically. Countries that seek out foreign technologies in effect supplement their own R&D activities by drawing on the innovations produced by R&D carried out elsewhere. If other countries are more active acquirers of foreign technologies than the U.S., they probably can maintain a given rate of technological progress with a lower investment in R&D. 15/

Finally, a comparison of Figure 18 with Tables 3 and 6 suggests that the volume of sale of licenses to unaffiliated subsidiaries is increasing at the same time that U.S. competitiveness in many product markets is deteriorating. This comparison highlights the distinction between R&D and innovation. While increased R&D might raise U.S. sales of new technologies (through licenses and so forth), it would not necessarily boost the competitiveness of U.S. products if other countries are more aggressive in transforming such R&D into new products and processes that are widely diffused throughout their economies.

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15. This argument is made very forcefully in Raymond Vernon, "Gone Are the Cash Cows of Yesteryear," Harvard Business Review (November-December, 1980), pp. 150-155.

CHAPTER IV. CURRENT TRENDS IN R&D SPENDING

Direct funding is the most visible and arguably the most crucial form of government R&D support. 1/ It is also the form over which the Congress has the most immediate control. This chapter presents an overview of current trends in R&D spending, especially by the federal government. It concentrates on a general description of federal R&D funding, based on the budgets of government agencies that are major sponsors of R&D. In addition, it discusses alternative approaches to constructing federal R&D budgets, based on the type of work carried out rather than the source of funding. A companion CBO report presents a detailed evaluation of the R&D programs in the Administration's budget request for fiscal year 1985. 2/ Rather than duplicate the material presented there, this chapter concentrates on the pattern of R&D spending between 1980 and 1984. For 1984, budget data are presented for both the original Administration request and the estimated funding levels authorized by the Congress.

OVERVIEW

The Administration bases its R&D policy on the public goods and pipeline rationales discussed in Chapter II: government funding should focus on public goods, especially defense, and on activities that the market is unlikely to support, especially basic research, leaving applied research and development to the private sector. One of the major trends in recent civilian R&D budgets, therefore, is a fairly sharp shift away from development and toward basic research. Moreover, civilian R&D funding has not been exempt from the general budgetary pressures on nondefense activities,

1. Other forms of government support of R&D and innovation are discussed in Chapter V.

2. Congressional Budget Office, Research and Development in the Proposed Fiscal Year 1985 Budget (March 1984).

so that civilian R&D support has been subject to close scrutiny. 3/ In addition, defense increasingly dominates the federal R&D effort. Defense-related R&D accounts for almost 70 percent of total federal R&D spending in the budget request for fiscal year 1985--the highest defense share since 1962.

Applied research is the orphan category in the Administration's R&D budgets. Development spending has risen because of the defense buildup, while the Administration has now reaffirmed governmental responsibility for funding basic research. The applied category has lost the most ground in terms of its share of federal R&D funds, despite the fact that applied research may be the key link in determining the rate at which laboratory research is transformed into commercial products or processes.

Since the late 1970s, the private sector has boosted its real R&D expenditures at a rate exceeding the postwar norm. Greater private commitment to R&D predates recent changes in macroeconomic policy, so that its underlying causes probably stem from such factors as increased international competition and greater recognition of the importance of R&D for dynamic competitiveness. Increased business support for R&D is particularly important in light of reduced federal support for civilian applied research and development.

Table 7 presents total R&D budgets for fiscal years 1980, 1982, and 1984. The first set of columns relating to 1984 refers to the Administration's budget request, presented to the Congress in January 1983, while the second set of columns refers to the funding levels authorized by the Congress. The data presented in Table 7 are divided according to whether the R&D is oriented toward defense or nondefense applications. The table also describes the percent shares of basic, applied, and development

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3. See, for instance, G. Keyworth, "Federal R&D: Not An Entitlement," Science, vol. 219 (February 18, 1983), p. 801. Keyworth is Science Adviser to the President and Director of the Office of Science and Technology Policy; and G.J. Knezo, Science Policy and Funding in the Reagan Administration, Congressional Research Service Issue Brief No. IB82108 (updated January 6, 1984).

TABLE 7. NOMINAL AND REAL PATTERNS OF R&D SPENDING BY TYPE AND CATEGORY, FISCAL YEARS 1980, 1982, AND 1984 (In billions of dollars in budget authority and percents)

Type and Category	1980 a/ Current Dollars	1980 a/ 1982 Dollars	1980 a/ Percent Share	1982 a/ Current Dollars	1982 a/ Percent Share	1984 b/ Current Dollars	1984 b/ 1982 Dollars	1984 b/ Percent Share	1984 c/ Current Dollars	1984 c/ 1982 Dollars	1984 c/ Percent Share
All R&D											
Basic	4.7	5.5	14.9	5.4	15.1	6.6	6.1	14.5	7.2	6.6	16.1
Applied	6.9	8.1	21.8	7.4	20.5	8.0	7.3	17.5	8.4	7.7	18.9
Development	20.0	23.5	63.2	23.3	64.5	31.2	28.7	68.1	29.0	26.6	65.0
Total	31.6	37.1	---	36.1	---	45.8	42.1	---	44.5	40.9	---
Defense d/											
Basic	0.6	0.6	3.7	0.7	3.2	0.9	0.8	2.7	0.8	0.8	2.9
Applied	1.9	2.2	12.7	2.4	11.0	2.9	2.6	9.0	2.8	2.6	9.6
Development	12.5	14.7	83.7	18.9	85.8	28.2	25.9	88.3	25.6	23.5	87.5
Total	14.9	17.6	47.3	22.1	61.1	32.0	29.4	69.8	29.3	26.9	65.8
Nondefense											
Basic	4.2	4.9	25.1	4.7	33.7	5.7	5.3	41.5	6.3	5.8	41.6
Applied	5.0	5.9	30.1	5.0	35.3	5.1	4.7	37.0	5.6	5.1	36.6
Development	7.5	8.8	44.9	4.4	31.0	3.0	2.7	21.5	3.3	3.1	21.9
Total	16.6	19.5	52.7	14.1	38.9	13.8	12.7	30.2	15.2	14.0	34.2

SOURCE: Congressional Budget Office from data provided by the Office of Management and Budget.

a. Actual.
b. Budget request.
c. Estimate (after Congressional action).
d. Comprises R&D spending by Department of Defense and military programs in the Department of Energy.

activities in total funding as well as real spending levels in 1982 dollars, using CBO estimates of the GNP implicit price deflator. 4/

As can be seen from Table 7, the pattern of R&D funding is shaped by the same pressures that mold the overall federal budget. This means, first of all, that R&D funding has been highly volatile in recent years. Aggregate R&D spending has increased during the present Administration, although real spending was cut in the first full budget submitted by the Administration. Subsequent budgets have increasingly favored R&D spending, so that the request for fiscal year 1984 represented an increase of 45 percent over 1980 levels in current dollars--or a projected real increase of about 13 percent. Congressional action reduced 1984 R&D funding 3 percent below the level requested by the President, so that estimated 1984 funding is currently 41 percent above the 1980 level (an increase of 10 percent in real terms).

The Administration's R&D budgets reflect a consistent application of the traditional rationale for government R&D funding. To a great extent, an effort has been made to limit government funding to missions that are clearly the responsibility of government, especially the provision of public goods. Defense is the best example of this trend and increasingly dominates aggregate federal R&D funding. In addition, after cutting civilian basic research funding in fiscal years 1981 and 1982, the Administration has embraced the traditional view that basic research is a governmental responsibility, while the more market-oriented activities of applied research and development should be left to the private sector. In short, the Administration's policy for civilian R&D is based on the pipeline concept described in Chapter II. 5/ A strong emphasis on defense and an effort to rely as much as possible on the market are the most significant trends in current R&D budgets.

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4. Estimating the impact of inflation is not an exact science, and this caveat obviously applies with even greater force to projected rates of inflation. As was pointed out in Chapter II, the deflator used throughout this report is the GNP implicit price deflator, although there are some arguments that would favor the use of a more complex price index, oriented specifically towards the price changes in R&D inputs. Such R&D price deflators generally suggest a higher rate of inflation for R&D activities than in the economy as a whole.

5. See G. Keyworth, "Federal R&D and Industrial Policy," Science, vol. 220 (June 10, 1983), pp. 1122-25.

Defense-related R&D has grown with the defense budget. Including Department of Energy (DOE) defense-related spending, R&D for defense grew from 48 percent of the R&D budget in 1980 to 70 percent in the Administration's fiscal year 1984 budget request. The Congress has authorized smaller increases in defense R&D, so that the current estimate of the defense share for 1984 is 66 percent. Nevertheless, the overall trend reflects the Administration's emphasis on such activities. Compared with 1980, the fiscal year 1984 budget includes a 96 percent increase in defense-related R&D spending (from $14.9 billion in fiscal year 1980 to $29.3 billion in the budget for fiscal year 1984), or an estimated real increase of 53 percent. By a small margin, the nominal increase in DoD R&D spending has been even greater, and its rate of growth--98 percent--exceeds the growth in the overall DoD budget, which increased 81 percent from 1980 to 1984 (in current dollars).

Defense R&D is heavily oriented toward development activities, particularly the construction and testing of prototypes for advanced weaponry. Of all the major government agencies that fund significant amounts of R&D, [6] DoD spends by far the smallest proportion on basic and applied research. Moreover, the predominance of development within the defense R&D budget has been increasing. Whereas development activities absorbed 84 percent of the defense-related R&D budget in fiscal year 1980, they account for 88 percent in fiscal year 1984. Thus, the emphasis on defense spending entails a corresponding shift in the aggregate R&D budget, favoring development over basic and applied research. Leaving out defense-related development funding, real R&D funding in the fiscal year 1984 budget is only 78 percent of the 1980 level--representing a decline in current dollars from $19.1 billion in 1980 to $18.9 billion in 1984.

To some extent, the Administration has compensated for the defense-based boost in development through increased funding for basic research in most departmental budgets in its 1983 and 1984 budget requests. Even though basic research makes up a declining share of the defense R&D budget, the fiscal year 1984 DoD budget request for basic research included a real increase of 23 percent above the 1980 level. In 1984, the Congress provided 97 percent of requested DoD basic research funds.

For all basic research, both defense and civilian, the Administration request for 1984 represented a real increase of 10 percent over the 1980 level (from $4.7 billion to $6.6 billion in current dollars). The Congress has

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6. NASA, NSF, EPA, and the Departments of Defense, Agriculture, Health and Human Services, Energy, Interior, Transportation, and Commerce.

provided even more funding. The current estimate for all 1984 basic research funding is $7.2 billion, representing a real increase of 19 percent compared with 1980. Real funding for civilian basic research also has been increased 19 percent over the same period and 8 percent from 1983 to 1984, reflecting current-dollar funding levels of $4.2 billion in 1980 and an estimated $5.6 billion in 1983 and $6.3 billion in 1984. The only agency that showed a significant decrease in requested funding for basic research has been NASA, although the share of basic research in NASA's total R&D budget showed a significant increase. This reported shift in NASA funding is misleading, however, because of the above-mentioned reallocation of shuttle expenditures from R&D to operations.

R&D SPENDING BY AGENCY

Federal spending for research and development is embedded in the separate budgets of numerous departments and agencies, so that an R&D budget must be constructed from the information provided by many government agencies. The budgets of most federal agencies are organized in terms of mission-oriented programs, of which R&D activities are only one part. The National Science Foundation (NSF) and the National Aeronautics and Space Administration (NASA) are the only major government agencies that support research and development as their primary mission. The NSF is also one of two government agencies that compiles a consolidated R&D budget--the other being the Office of Management and Budget (OMB). The American Association for the Advancement of Science (AAAS) also prepares a federal R&D budget that is, in many ways, the most comprehensive and sophisticated of the three. Like the NSF R&D budget, however, it is based on material provided to OMB by the various government agencies. 7/

The fact that total R&D spending must be culled from many separate agency budgets introduces some arbitrariness into the specification of federal R&D support. Individual agencies make their own judgments about

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7. Each March, AAAS publishes a compilation of proposed federal R&D funding for the next fiscal year. These reports contain detailed evaluations of trends in agency R&D funding. OMB's compilation of R&D funding is currently presented in "Special Analysis K" accompanying the President's annual budget submission. In addition, the Congressional Research Service tracks R&D spending throughout the budget process; see, for example, Congressional Research Service, Federal Funding for Research and Development in Major Departments and Agencies, Fiscal Year 1984, Issue Brief Number IB83057 (updated January 6, 1984).

allocating R&D funding among the categories of basic research, applied research, and development, and about separating R&D expenses from operating costs. Decisions to revise program allocations can upset the analysis of data collected over a number of years. This was the case, for instance, with the basic research budget of the Environmental Protection Agency (EPA), which increased from $11 million in fiscal year 1981 to $33 million in 1982 as a result of recategorizing programs. Similar difficulties are now reflected in the NASA budget, which reallocated space shuttle spending from R&D to operations as of the fiscal year 1984 budget (retroactive to 1982), on the grounds that NASA plans to operate the shuttle as a commercial venture. While such reallocations show up as significant shifts in departmental R&D spending, they need not reflect similar changes in the kinds of work the government supports.

As one would expect considering the recent volatility in the federal budget as a whole, agency R&D budgets have been subject to very diverse pressures and trends since 1980. Overall, the pattern of agency R&D funding reflects the general trends discussed in the preceding section. Some agencies (Defense, Transportation and the National Science Foundation) have experienced healthy increases in their R&D budgets, even in real terms. These agencies carry out R&D activities for which, in the Administration's eyes, the government should be responsible. Other agencies (Agriculture and Health and Human Services) have shown nominal gains but real declines. R&D spending at the Department of Energy has been approximately stable in current dollar terms, reflecting a significant decline in real terms--especially in nondefense activities. Finally, there are some agencies whose R&D budgets have been cut in both real and nominal terms: NASA, Interior, EPA, and Commerce. The details of current agency R&D budgets are discussed in CBO's Research and Funding in the Proposed Fiscal Year 1985 Budget; only their most significant features are presented here.

Department of Defense. As was suggested in the previous section, R&D funding by the Department of Defense has enjoyed substantial and across-the-board increases, so that DoD now spends some $27 billion (in 1984 budget authority) on R&D. The increases in defense-related R&D have been so substantial that all types have enjoyed real increases. Abstracting from branch-of-service spending, DoD breaks down its R&D budget into the following categories, with their share of total DoD R&D budget authority for fiscal year 1984 in parentheses:

- Technology base (11 percent);
- Advanced technology development (5 percent);
- Strategic programs (29 percent);

- Tactical programs (29 percent);
- Intelligence and communications (12 percent);
- Program management and support (12 percent); and
- Other (2 percent).

Between 1980 and 1984, the categories that enjoyed the most significant growth were strategic programs (up 360 percent) and intelligence and communications (up 300 percent). Strategic programs comprise the MX Peacekeeper and Trident missile programs, advanced bombers (B1 and Stealth), and the space-based antiballistic missile system proposed in the 1985 budget, which will significantly boost DoD R&D spending in the future. 8/ Funding for tactical programs, by contrast, has grown more slowly--51 percent since 1980. The technology base category has grown the least--34 percent since 1980. This category contains most DoD basic research as well as most of the applied programs (such as research in very high-speed integrated circuits, artificial intelligence, and super computers) that affect directly the performance of the civilian economy. Related development projects are found in the advanced technology development category. In recent years technology-base programs have typically been reduced when the Congress has sought to cut defense spending below the levels requested by the Administration.

Department of Transportation (DOT). About 55 percent of the DOT R&D budget (a total of $0.45 billion for fiscal year 1984) is devoted to Federal Aviation Administration (FAA) activities, and FAA R&D far outweighs the R&D sponsored by other DOT departments. Higher R&D funding for FAA programs is based on the same public-goods rationale that underlies federal defense-related R&D support. Most of the FAA R&D is devoted to the development of improved air traffic control systems, and these costs are eventually recouped through a trust fund supported by fees and taxes on the users of FAA services.

National Science Foundation. NSF R&D funding ($1.2 billion in fiscal year 1984 budget authority) is devoted almost exclusively (over 95 percent) to the support of basic research in academic institutions. Although real spending for NSF was cut in the first years of the current Administration, NSF's budget now seems relatively secure, at least in the aggregate.

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8. See R.J. Smith, "The Search for a Nuclear Sanctuary," a two-part article published in Science, vol. 221 (July 1, 1983 and July 8, 1983), pp. 30-32 and pp. 133-38.

Nevertheless, the volatile pattern of NSF funding since 1980 may have disrupted long-term research efforts. Moreover, as will be discussed in the next section of this chapter, some fields of research have been less favored and have shown real declines in funding.

Department of Health and Human Services. The clearest case of disagreement between the Administration and the Congress over R&D funding is the National Institutes of Health (NIH), which account for over 85 percent of the total R&D budget of the Department of Health and Human Services (HHS). Other health agencies within this department (the Center for Disease Control, the Food and Drug Administration, and the Alcohol, Drug Abuse and Mental Health Administration) are also major funders of R&D, while human services activities account for only about 1 percent of HHS R&D. The Administration's 1984 request included $4.4 billion in budget authority for HHS R&D (32 percent of total civilian R&D funding). The Congress provided $4.8 billion for these activities.

The Congress has traditionally been a strong supporter of health research and the NIH, and basic medical research has enjoyed a special status outside the NSF framework. Nevertheless, the expense of health-related R&D (HHS spends more on civilian research than any other agency) has made it a target for cost-reduction efforts. The Administration has sought to reduce funding for new research grants, either by limiting new projects below the Carter Administration's annual target of 5,000 or by providing partial funding for a larger number of grants. The Congress has restored HHS funding, so that R&D funding by this agency shows only a slight real reduction compared with 1980.

Department of Agriculture. As is the case with HHS, relatively constant real spending levels for R&D are also evident at the Department of Agriculture (USDA). The Administration requested $850 million for USDA R&D in fiscal year 1984, and the Congress increased this figure to $870 million; 1984 R&D at the USDA is still 2 percent below the 1980 level in real terms, however. Largely through the Agricultural Research Service and the Cooperative State Research Service, the federal government has provided technological support to the agricultural sector since the 19th century. Although there are few a priori grounds for supporting civilian R&D in this sector and not in others, these programs' long tradition, their generally recognized success, and the political strength of the farm sector have made them less vulnerable to budgetary pressures.

National Aeronautics and Space Administration. NASA spending has also been flat, despite the fact that reported R&D funding shows a spectacular decrease, from $5.1 billion in fiscal year 1980 to $2.9 billion in 1984 (up from an original Administration request of $2.5 billion). This is a statistical artifact, reflecting the partial reallocation of space shuttle funding from R&D to operations. Before the fiscal year 1984 budget request, all NASA funding was treated as R&D. Since NASA's total budget request for fiscal year 1984 called for $6.7 billion in obligations, this should be compared with total NASA obligations of $5.8 billion in 1980, suggesting a real decline of 10 percent. The reallocation of shuttle funding reflects the Administration's desire to commercialize and potentially privatize many aspects of the shuttle program. Without another major commitment, possibly the manned space station proposed in the fiscal year 1985 budget, NASA R&D funding will tend to decrease.

Since at least the late 1970s, shuttle activities have provided the impetus for the NASA budget. The high priority given to the shuttle has reduced the funds available for other programs, such as Landsat (which has been transferred to the Department of Commerce), planetary exploration, and aeronautics R&D. The pressure on these programs has abated somewhat since the shuttle has become operational, and new projects are now being funded on a limited scale. Moreover, despite earlier efforts to cut civilian-oriented aeronautical R&D, the Administration now supports it. 9/ As with agricultural programs, the favored treatment of aeronautics may reflect the fact that these programs have a long tradition, dating to NASA's predecessor agency, the National Advisory Committee on Aeronautics.

Department of Energy. The largest cuts in civilian R&D have been at the Department of Energy (DOE). The fiscal year 1984 budget request for DOE R&D amounted to $4.7 billion, $3.3 billion of which was for civilian activities. The Congress, as it has in past years, restored funding for many civilian energy technologies (such as solar and fossil energy sources) while providing less funding for nuclear technologies than the Administration requested. This pattern was particularly evident in 1984, when the Congress eliminated funding for the Clinch River Breeder Reactor. Nevertheless, overall funding for DOE R&D has reflected the Administration's budget priorities: increased defense spending and reductions in civilian development.

Compared with 1980, the overall DOE R&D budget has fallen 21 percent in real terms, while real civilian R&D has dropped 36 percent. To a large extent, these trends stem from the Administration's unwillingness to support commercially oriented R&D, so that budget requests have included

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9. Executive Office of the President, Office of Science and Technology Policy, Aeronautical Research and Technology Policy (November 1982).

major cuts in civilian development funding (down 70 percent in real terms), particularly in nonnuclear technologies.

While major cuts were made in DOE energy development funding, real funding for both basic and applied research increased over 1980 levels. As a result, the DOE R&D budget stands out as the clearest example of the Administration's efforts to restrict government R&D funding to activities the market is unlikely to support. Major cuts in development projects, many of which have failed to attract financial commitments from private firms, have enabled the Administration to reduce DOE spending while increasing support for basic and applied research.

Department of Commerce. The Department of Commerce funds a significant amount of R&D through the National Oceanic and Atmospheric Administration (NOAA) and the National Bureau of Standards (NBS), which account for almost 95 percent of Commerce's total R&D spending. These agencies, especially NOAA, have been under severe budgetary pressure; the Administration requested $240 million for Department of Commerce R&D in fiscal year 1984, down from actual funding of $324 million in 1983. The Congress has restored the department's R&D funding to some extent, so that estimated 1984 funding is now $352 million. Real R&D funding by the Department of Commerce in fiscal year 1984 is three-quarters the 1980 level. Funding cuts may be particularly significant in the NBS case, since the Bureau is the sole government agency with a mission to provide industry with broad-based technological support, particularly in applied research.

Other. Finally, severe proportional cuts in funding have been made in the R&D budgets of several agencies that are relatively minor sources of civilian R&D support, such as the Department of Interior and the Environmental Protection Agency. For 1984, R&D funding at the Department of Interior amounts to $388 million (compared with a 1984 request of $334 million), down from $404 million in 1980. This represents a real decline of 25 percent since 1980. At the EPA, R&D funding is $248 million in 1984 (compared with a request for $207 million)--more than 40 percent below the 1980 level in real terms. For a more comprehensive discussion of agency R&D budgets, readers should consult Research and Development Funding in the Proposed Fiscal Year 1985 Budget.

OUTPUT-BASED DESCRIPTIONS OF FEDERAL R&D SPENDING

Government agencies are required to report R&D spending by type (basic, applied, development) to the Office of Management and Budget, so that this information is readily available. Insofar as increased innovation is an explicit policy goal, however, it may also be appropriate to describe federal spending patterns according to alternative criteria, especially in terms of the character of the work performed (the output) rather than the source of funding (the input). In principle, the source of funding within the government is irrelevant to the economic impact of R&D, although different managerial practices may distort this principle in practice.

Federal Funding of Scientific Disciplines

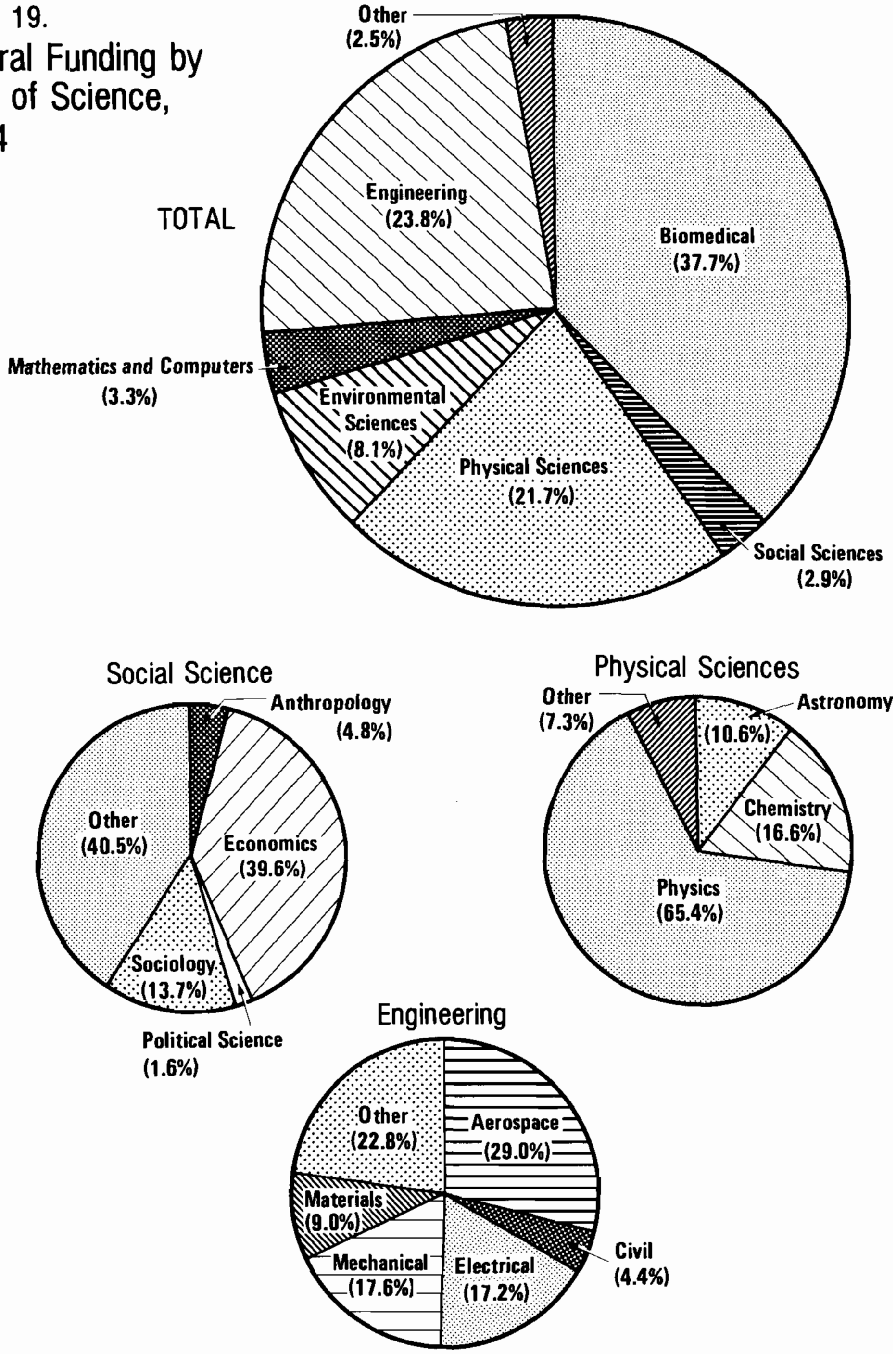
For basic (and some applied) research, an output-oriented R&D budget is based on the field of science. The National Science Foundation maintains records of federal research spending in terms of scientific field, largely because its principal constituency, the academic community, is organized along these lines. Once R&D has reached the development stage, it typically combines the skills and insights of a variety of disciplines. Moreover, development is characteristically funded for commercial reasons and carried out by industry rather than by the academic community. For these reasons, it is impossible to disaggregate development funding (and even some applied research) along the characteristic lines of academic departments or scientific disciplines.

Figure 19 shows the pattern of current-dollar research funding by field of science for the fiscal year 1984 budget request. The shares shown in these graphs have remained relatively constant over time, as has the overall level of real spending. Data confirming this are presented in Table 8. Since the mid-1960s, biomedical research (including psychology) has increased its share, largely at the expense of engineering. Mathematics and computer sciences have also gained, while the social science share has fallen.

The distribution of funding has also remained fairly consistent on a more disaggregated level, as is shown in the second part of Table 8. The most significant trend in current field-of-science funding, however, is a reemphasis of the "hard" sciences (such as physics), reflecting their importance for defense. Social and environmental sciences have been cut sharply since 1980, both in real terms and as a percent of field-of-science funding. Even within the hard-science category of the physical sciences, the distribution of funding has shifted more sharply since 1980 than in the preceding 15 years. Physics received 58 percent of the total in 1967, 59 percent in 1980, and a requested 65 percent in 1984. Chemistry's share, which held roughly constant from 1967 (24 percent) to 1980 (23 percent), is projected to fall to 17 percent in fiscal year 1984.

Although the data for fiscal year 1984 are estimated, they buttress the observation that federal R&D spending is currently undergoing a reorientation that is significant by historical standards. Moreover, they reflect the

Figure 19.
Federal Funding by Field of Science, 1984



SOURCE: National Science Foundation.

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TABLE 8. FEDERAL BASIC AND APPLIED RESEARCH FUNDING, BY FIELD OF SCIENCE FOR CALENDAR YEARS 1967, 1980, AND 1984 (In percent shares and total funding in current and 1981 dollars)

Field	1967 a/	1980 a/	1984 b/
		Major Fields	
Biology, Medicine, Psychology	31.4	37.9	37.7
Physical Sciences	20.3	17.3	21.7
Mathematics and Computer Sciences	2.8	2.1	3.3
Environmental Sciences	8.2	10.9	8.1
Social Sciences	4.1	4.5	2.9
Engineering	30.8	24.4	23.8
Other	2.5	3.0	2.5
Total	100.0	100.0	100.0
Addendum: Total Dollar Funding			
In billions of current dollars	4.6	11.6	14.7
In billions of 1981 dollars	11.5	12.7	12.6
		Selected Fields	
Physical Sciences			
Physics	58.2	59.1	65.4
Chemistry	24.1	22.7	16.6
Astronomy	12.8	14.3	10.6
Other	4.9	3.9	7.3
Total	100.0	100.0	100.0
Addendum: Total Dollar Funding			
In billions of current dollars	0.9	2.0	3.2
In billions of 1981 dollars	2.3	2.2	2.7

(Continued)

SOURCE: National Science Foundation.

NOTE: Percent shares may not add to 100 percent because of rounding.

TABLE 8. (Continued)

Field	1967 a/	1980 a/	1984 b/
		Selected Fields	
Social Sciences			
Economics	36.5	36.9	39.8
Sociology	25.4	13.6	13.7
Anthropology	5.8	3.3	4.6
Political Science	---	2.3	1.6
Other	32.3	44.0	40.5
Total	100.0	100.0	100.0
Addendum: Total Dollar Funding			
In billions of current dollars	0.2	0.5	0.4
In billions of 1981 dollars	0.5	0.6	0.4
Engineering			
Aerospace	38.8	35.7	33.1
Electrical	18.5	18.3	19.6
Materials	8.5	8.3	10.3
Mechanical	8.0	7.3	5.8
Civil	3.0	5.6	5.0
Other	23.1	24.7	26.1
Total	100.0	100.0	100.0
Addendum: Total Dollar Funding			
In billions of current dollars	1.4	2.8	3.5
In billions of 1981 dollars	3.5	3.1	3.0

a. Actual.

b. Estimated.

reemphasis of defense that is evident in the agency-specific depiction of the federal R&D budget. When contrasted with the more stable historical patterns, current field-of-science data also illustrate the uncertainty about future budgets that has concerned some members of the research community.

Federal Funding of Specific Technologies

Field-of-science funding concerns research, especially basic research, and there is no assurance that increased basic research leads automatically to increased innovation. Innovation depends more critically on applied research and development and the subsequent diffusion of technical knowledge, for which the relevant outputs are technologies rather than scientific fields. A number of agencies typically provide funds for any given technology. R&D in advanced electronics, the most obvious example, is funded as part of the mission of several agencies: Defense, Energy, NASA, the National Bureau of Standards, and so on. A technology-based R&D budget is therefore the developmental complement to a field-of-science budget for research. More important, it is well-suited to evaluating the economic impact of federal R&D funding.

Unfortunately, no comprehensive, technology-based evaluation of the federal R&D budget is available; in itself, this fact suggests that the government as a whole has not sought to promote technological progress for its own sake. By default, technological innovation is almost universally treated as a by-product of the mission-oriented activities of federal agencies.

Table 9 presents a partial depiction of agency funding in particular technology areas: computer science, materials science, engineering, and bioengineering. In order to suggest the trends operating in these areas, funding levels are shown for fiscal years 1980 and 1983. The technologies listed in these tables were selected to reflect a broad range of activities with significant economic potential. While most of these technologies would commonly be referred to as "high-tech," the list includes fields (for example, metallurgy) that are relevant to more traditional manufacturing sectors, which still far outweigh high-tech sectors in terms of their economic impact (jobs, value added, and so forth).

The data presented in Table 9 should be used with some care. They are estimates provided by the budget offices of the agencies concerned, and since no agency regularly collects or maintains data on funding by technology, these data represent approximate figures, pieced together from information collected in a different, more mission-oriented format. Most

TABLE 9. ESTIMATED FEDERAL FUNDING OF SPECIFIC TECHNOLOGIES BY MAJOR R&D AGENCIES, FISCAL YEARS 1980 AND 1983 (In millions of current dollars) a/

Technology	National Science Foundation		National Bureau of Standards		National Aeronautics and Space Administration		National Institutes of Health		Department of Agriculture		Department of Energy		Total for Listed Agencies	
	1980	1983	1980	1983	1980	1983	1980	1983	1980	1983	1980	1983	1980	1983
Computer Science														
Theory	2.7	6.2	2.0	2.2	0.0	2.9	N/A	N/A	0.0	0.0	N/A	N/A	N/A	N/A
Hardware	3.2	3.1	2.7	2.6	2.3	10.8	N/A	N/A	0.0	0.0	N/A	N/A	N/A	N/A
Software	6.4	6.1	3.6	3.5	3.6	4.9	N/A	N/A	0.0	0.0	N/A	N/A	N/A	N/A
Other	6.2	13.7	0.0	0.0	0.0	0.0	N/A	N/A	0.0	0.0	N/A	N/A	N/A	N/A
Total	18.5	29.1	8.3	8.4	5.9	18.6	78.0	85.0	0.0	0.0	3.0	8.3	113.7	149.4
Materials Science														
Solid state	12.8	17.1	0.8	1.0	1.4	0.9	0.0	0.0	0.0	0.0	N/A	N/A	N/A	N/A
Metallurgy	6.9	7.9	0.6	1.0	10.5	12.0	0.0	0.0	0.0	0.0	N/A	N/A	N/A	N/A
Ceramics	3.6	4.5	0.3	1.7	7.6	4.0	0.0	0.0	0.0	0.0	N/A	N/A	N/A	N/A
Composite	N/A	N/A	0.1	0.6	10.9	10.0	0.0	0.0	0.0	0.0	N/A	N/A	N/A	N/A
Other	45.4	51.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	N/A	N/A	N/A	N/A
Total	68.7	80.8	1.8	4.3	30.4	26.9	0.0	0.0	0.0	0.0	96.0	120.2	196.9	232.2
Engineering														
Robotics	11.0	18.3	0.0	3.2	2.0	3.2	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A
CAD/CAM b/ c/			0.1	0.2	0.2	0.8	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A
Chemical and process	16.0	22.3	2.3	4.2	0.0	0.0	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A
Other	49.6	60.2	0.0	0.0	0.0	0.0	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A
Total	76.6	100.8	2.4	7.6	2.2	4.0	0.0	0.0	8.7	10.3	193.1	477.0	283.0	599.7
Bioengineering	40.8	47.4	0.9	2.0	0.0	0.0	170.0	498.0	20.2	32.9	0.0	0.0	231.9	580.3

SOURCE: Data provided by agency budget offices.

NOTE: N/A = not available.

a. The Department of Defense is unable to break out its R&D funding according to specific technologies and, therefore, is not included in this table.
b. NSF does not disaggregate these categories.
c. CAD/CAM = computer aided design and computer aided manufacturing.

significantly, the absence of data from the Department of Defense seriously compromises the analytical usefulness of Table 9. The enormous size of the DoD R&D budget complicates any effort to disaggregate it in novel ways and thus prohibits the inclusion of information on DoD funding of specific technologies. DoD funds for R&D swamp the R&D support provided by other agencies. For example, in fiscal year 1983, DoD's R&D budget was almost twice the size of the combined nondefense R&D budgets of the agencies included in Table 9.

Because of these limitations, the data presented in Table 9 are illustrative rather than comprehensive. Nevertheless, they suggest several points that can be made about the pattern of federal support for specific technologies and about the prospects for developing a technology-based R&D budget.

First, a technology-based approach to constructing an R&D budget must confront the problem of applying consistent definitions of the technologies being monitored. This is particularly true of more generic technologies. Computers, for instance, have extremely broad technological applications, so that it is very difficult to allocate more basic computer research among the various technologies of robotics, computer aided design and computer aided manufacturing (CAD/CAM), and so on. In principle, allocating R&D activities by technology is not qualitatively more difficult than allocating funds according to the standard paradigm of basic research, applied research, and development. Since no agency collects technology-based data, however, technology definitions are not standardized. Moreover, even with standardized technology definitions, the problem of tying basic scientific research to specific technological applications will remain. Because of the organizational structure of universities, data on R&D funding by field of science is relatively easy to collect. Unfortunately, no corresponding institutional pattern simplifies the problem of identifying spending programs by technology.

Second, the difficulty of tracking technology-based spending patterns suggests that there may be a substantial amount of duplicated effort in federal programs. At the very least, there is no institutional mechanism for avoiding interagency duplication. Safeguards against duplication are informal, and in some instances rely on contractors--whether in industry or in the academic community--to stay abreast of ongoing work in the field concerned. It could be argued, however, that some amount of duplication is beneficial, since it diversifies the risk inherent in pursuing technological advances.

As was pointed out in the previous chapter, the mission orientation of federal agencies shapes the pattern of the R&D support they provide to industry, and the same point applies to the support of specific technologies. This is suggested in Table 9 by the discrepancy between the funding provided by NASA and that provided by the National Bureau of Standards (NBS). The Bureau, whose mission revolves around measurement issues, is the government institution with the broadest responsibility for supporting civilian technology (although this responsibility is still much less explicit than the NSF role in the basic research area). Yet its funding is, in many areas, much less than the funding available from an R&D agency with a more specific mission, such as NASA. In materials, for instance, the NASA budget is more than 15 times as great as the NBS budget. This means that a certain type of materials R&D--namely, that relevant to aerospace technologies--is supported to a far greater extent than other types. The NASA metallurgy R&D budget, for instance, is almost 20 times as great as the NBS metallurgy budget, so that the government funds R&D in the exotic alloys used in the aerospace industry to a far greater extent than it funds R&D in carbon steelmaking. This inference, which can be gleaned from Table 9, corroborates in technology terms the industry pattern of federal R&D funding discussed in the preceding chapter.

RECENT TRENDS IN PRIVATE R&D SPENDING

Data on private R&D spending are generally less reliable than data on federal programs, and private reporting is also less timely than is the case for the federal budget. While official data on private R&D spending are eventually collected by NSF, the earliest estimates of private R&D spending are published by the business press. Business Week estimates are presented in Table 10.

It should be stressed at the outset that these data are not directly comparable to the information presented in Chapter III. Business Week industry definitions are similar but not identical to NSF definitions, coverage may change from year to year, and companies with several lines of business (and therefore with R&D in several areas) are assigned to the industry that represents their principal business activity. The data presented in Table 10 should, therefore, be viewed as indicative of trends in private R&D support rather than as an extension of or substitute for NSF data.

With these caveats in mind, Table 10 strongly suggests that private firms are generally increasing their commitment to R&D. This trend has been largely sustained even through the extremely severe recession of 1982, although the data on R&D intensity for 1982 may be inflated by the interaction of declining sales due to the recession and the fact that 1982

TABLE 10. ESTIMATED PRIVATE R&D SPENDING AS A PERCENT OF SALES, CALENDAR YEARS 1979-1982

Industry	1979	1980	1981	1982
Aerospace	4.2	4.5	4.8	5.1
Automobiles	3.2	4.0	3.7	4.0
Chemicals	2.3	2.4	2.5	2.9
Drugs	4.8	4.9	5.3	6.0
Electrical	2.8	2.8	2.9	2.8
Electronics	2.5	2.9	3.1	5.3
Petroleum	0.4	0.4	0.5	0.5
Computers and Peripherals	6.1	6.3	6.4	6.8
Office Equipment	4.2	4.3	5.0	5.1
Instruments	3.9	4.2	4.6	5.2
Machinery	1.6	1.6	1.9	2.6
Nonferrous Metals	0.5	0.9	1.1	1.2
Semiconductors	5.7	6.0	7.1	7.8
Steel	0.6	0.6	0.6	0.7
Telecommunications	1.0	1.0	1.2	1.3
Textiles	0.6	0.5	0.4	0.6
Tire and Rubber	1.7	1.8	2.0	2.3

SOURCE: Business Week, (July 7, 1980, July 6, 1981, July 5, 1982, and June 20, 1983).

R&D spending levels were frequently set before the depth of the recession became apparent. Nevertheless, the private sector appears to be committed to increasing its R&D spending, perhaps because of the challenge of heightened international competition. In a period when the government is reducing its support for nonbasic civilian R&D, greater private funding is an encouraging and much needed development. The next chapter discusses current nonspending policies designed to boost private R&D and innovation.

CHAPTER V. GOVERNMENT ENCOURAGEMENT OF INNOVATION: TAX AND OTHER POLICIES

Besides its direct funding of R&D, the government also influences the technological performance of the economy through programs that encourage greater private commitment to R&D and innovation. Tax incentives can be used to reduce the cost of R&D activities to firms, thereby making such activities more attractive. Antitrust and patent policies can help lower some of the barriers to private innovation and R&D. Government procurement provides a large market that can influence the development of desirable technologies. In fact, few government actions--from environmental regulations to minimum-wage legislation to trade agreements--do not in some way affect innovative activity.

The most potent factors that affect private innovation decisions are probably beyond the reach of specific R&D policies. Expectations about macroeconomic conditions and the intensity of competition (or rivalry) within an industry may be the most significant determinants of its technological performance. 1/ In a strong economy, firms have the funds and the market prospects to justify increased commitments to R&D. Robust markets may have a counteracting effect, however, since they lessen the urgency to pursue new products and processes. This implies that private innovation is likely to be strongest under the dual conditions of a healthy macroeconomy and strong sectoral competition.

Fiscal and monetary policies therefore have a significant impact on private R&D. General tax policies affect corporate cash flow and thus the funds available to fund R&D internally. General investment incentives, such as accelerated depreciation allowances and investment tax credits, also tend to boost innovation and R&D. Policies affecting competition--antitrust enforcement, for example--are also important. Actions that weaken competitive forces, such as trade barriers, are likely to reduce the incentives for private R&D. Such indirect effects are rarely considered, but they

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1. Anecdotal evidence supporting this view can be found in a recent Business Week article (December 12, 1983, pp. 76-86) describing major increases in R&D funding by the Allied Corporation. No mention is made of increased governmental incentives among the factors that encouraged Allied to reorient its corporate strategy toward R&D and innovation.

may be more crucial determinants of technological performance than policies that explicitly target aid to R&D.

Compared with macroeconomic programs and policies that affect competitive conditions, specific federal R&D incentives, other than direct funding, are probably of secondary importance. Section 174 of the Internal Revenue Code, which allows firms to "expense" R&D costs, has been in effect for 30 years. 2/ According to estimates of the Congressional Joint Committee on Taxation (JCT), Section 174 will lower Treasury revenues by about $2.2 billion in fiscal year 1984. The revenue effect of more recent R&D tax incentives, such as the incremental R&D tax credit, is much smaller. Moreover, the specific features of the credit weaken its incentive effects.

This chapter concentrates on tax incentives, since these, like direct funding, have an immediate budgetary impact. The tax section is followed by a short discussion of two regulatory areas that significantly affect the overall innovative performance of the economy: antitrust enforcement and patent policies. The chapter closes with a brief discussion of the effects of government procurement on R&D.

TAX POLICIES

General tax policies help shape the incentives that govern private-sector activities, including R&D investments and innovation. From an economic perspective, R&D is an investment--that is, R&D comprises current expenditures that are undertaken to provide future rather than current benefits. Since 1954, however, Section 174 of the Internal Revenue Code has granted firms the option of expensing "qualified" R&D expenditures, defined as labor and materials costs. In effect, Section 174 places R&D investments on the same footing as production costs: R&D labor and materials costs can be deducted from taxable income in the same year that the costs are incurred, while R&D plant and equipment must be depreciated over a number of years. Section 174 thus offers a tax incentive for firms to invest in R&D activities.

Recent changes in the tax laws, especially through the Economic Recovery Tax Act of 1981 (ERTA), have increased the general attractiveness of investments in plant and equipment. Presumably, this should have a

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2. Expensing means that firms can deduct the full cost of qualified R&D expenditures in the year that the expenditures are made rather than depreciating them over a number of years.

positive effect on innovation. ERTA's impact on R&D, however, is complicated by the fact that its general investment incentives dilute the benefits of existing R&D incentives such as the expensing option. ERTA also includes specific R&D incentives, especially an incremental R&D tax credit, but the effects of such programs may not be great. Assessments of how the tax system affects R&D and innovation must consider the interaction of a wide range of tax provisions rather than specific R&D incentives alone.

General Tax Policies

Three basic arguments have been cited to support the view that effective macroeconomic policies, of which tax programs are a part, encourage innovation:

- First, economic expansion raises expected private returns to R&D and increases the cash flow available to firms for supporting R&D activities.

- Second, the increased investment in plant and equipment associated with economic growth typically implies that innovations are diffused more rapidly throughout the economy, since new machinery is likely to embody improved technology. Thus, even if no new R&D is undertaken, the fruits of previous R&D efforts may become more widespread.

- Third, high rates of investment tend to encourage innovations in capital-goods industries by increasing the demand for machinery and other equipment.

The first of these arguments hinges on the extent to which R&D is like other investments in following GNP trends. R&D spending may be governed by factors different from those that determine overall investment. Some economists have suggested that R&D is so much riskier than other forms of investment that firms are loathe to rely on borrowing for R&D. This suggests that R&D spending will be high when increased profitability generates strong cash flow, a condition that is characteristic of the early stages of a recovery. 3/ Alternatively, some believe that market downturns

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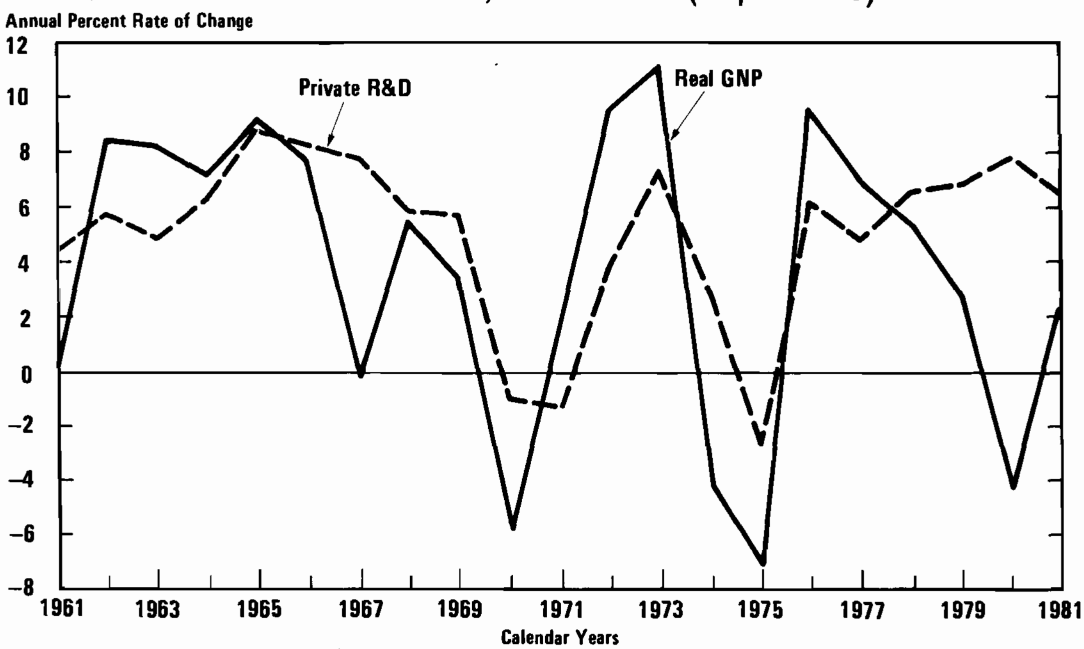
3. Studies of the cash-flow model are summarized in M. Kamien and N. Schwartz, Market Structure and Innovation (Cambridge, England: Cambridge University Press, 1982), pp. 95-98.

place pressure on firms to reduce their costs and therefore to seek new cost-saving technological processes. This would lead to an increase in innovation, if not in R&D, when the overall economy is stagnant or declining. 4/

The historical relationship between private R&D spending and macroeconomic performance supports the former view. This is shown in Figure 20, which relates the real rate of change in private R&D to the real rate

Figure 20.
Real GNP and Real Private R&D, 1961-1981 (In percents)



of GNP growth in the U. S. economy from 1956 to 1981. It should be pointed out that this figure shows nothing about the mix of R&D or its effectiveness. It does show that R&D spending has been strong despite slow GNP growth since the late 1970s. (This break with past patterns predates

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4. This is one of the underlying arguments of long-wave theorists of economic growth. See N. Kamrany and R. Day, eds., Economic Issues of the Eighties (Baltimore, Md.: Johns Hopkins Press, 1979) and G. Mensch, Stalemate in Technology (Ballinger: Cambridge, 1979).

changes in the tax laws, so that it must be ascribed to other factors, for example, heightened international competition.) Nevertheless, the evidence suggests that R&D spending is positively correlated with economic growth.

Policies that boost investment have more specific effects on R&D and innovation. Presumably they increase expenditures for R&D plant and equipment, speed the diffusion of innovations embodied in new equipment, and raise the expected return to R&D expenditures in capital-goods industries. Two aspects of the tax system are particularly relevant to investment decisions:

- The investment tax credit (ITC), an incentive that decreases the cost of investment in new plant and equipment by some percentage, now 6 or 10 percent; and

- The depreciation schedule, which determines the rate at which firms can recoup investment expenditures through the tax system.

The ITC is designed to reduce the relative price of plant and equipment, thus encouraging more capital investments. A depreciation schedule with shorter write-off periods encourages investment because it speeds the rate at which businesses can deduct expenditures on plant and equipment from taxable income and reduces the uncertainty connected with forecasting long-term trends in markets and in technology. The benefits of shorter as opposed to longer depreciation periods are greatly increased during inflationary periods, since depreciation deductions are based on historical cost rather than replacement cost. Studies of the effects of tax policies on investment show that a higher ITC and/or accelerated depreciation increase investment. The magnitude of this effect is disputed, although the ITC seems to be more significant than the depreciation schedule. 5/

The Economic Recovery Tax Act (ERTA) of 1981 instituted major changes in the nation's tax system. In regard to investment incentives, ERTA's most important provision was the institution of an accelerated capital recovery system (ACRS). Some of ERTA's investment incentives, such as safe-harbor leasing, were limited by the Tax Equity and Fiscal Responsibility Act (TEFRA) of 1982. Nevertheless, the net consequence of these two pieces of legislation was the implementation of significant increases in tax-based investment incentives relative to the pre-ERTA

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5. The controversy over the impact of tax incentives on investment and R&D is summarized at several points in National Science Foundation, Tax Policy and Investment in Innovation: A Colloquium (1983).

system. One would therefore expect these general changes in the tax laws to have the positive effects on innovation that were cited earlier in this section.

Nevertheless, a complete assessment of the R&D effects of ERTA/ TEFRA must be based on changes in the overall structure of tax incentives. On these grounds, the incentives for R&D may not have been greatly increased by general tax reforms. To the extent that R&D and other investments are substitutes, ACRS increases the incentives for all forms of investment and thus weakens the relative importance of the R&D tax incentives that were in place prior to ERTA. While the scale effect of ACRS on R&D may be positive, the substitution effect is negative. In other words, relative to the pre-ERTA system, ACRS tends to increase investment, including expenditures for R&D plant and equipment. At the same time, however, it also tends to shift business spending toward investment (for example, the purchase of a new piece of equipment) and away from operating expenses (for instance, hiring more workers). Since Section 174 treats R&D labor and materials costs as operating expenses, the relative impact of this incentive on R&D is diminished by ACRS.

Moreover, the negative substitution effect is strengthened by the fact that ACRS places R&D plant and equipment in the three-year depreciation category, which qualifies for a 6 percent rather than a 10 percent ITC. Under ERTA, the advantage of a shorter depreciation period was offset by the disadvantage of a smaller ITC. As a result, according to one estimate, the net impact on R&D of the ACRS in ERTA was negative. The passage of TEFRA, however, weakened the relative disincentive effects of ACRS, so that the net effect of ACRS on R&D investments now appears to be positive. 6/ Regardless of these considerations, however, ACRS is likely to improve the economy's technological performance by speeding the diffusion of new process technologies and by encouraging innovation in capital-goods sectors.

Specific Tax Incentives for Innovation

Until the recent changes in the tax laws, the major incentives that specifically targeted R&D were the following:

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6. See J. Barth, J. Cordes, and G. Tassey, "The Impact of Recent Changes in Tax Policy on Innovation and R&D" in Bozman, Crow, and Link, eds., Strategic Management of Industrial R&D (Lexington, Massachusetts: Lexington Heath, forthcoming).

- o Since 1954, firms have been able to choose between immediate expensing of R&D costs, excluding capital equipment, and depreciating those costs over five years. This option is based on Section 174 of the Internal Revenue Code.

- o Since the 1930s, firms have been able to deduct contributions to nonprofit establishments for the conduct of scientific work.

- o Since 1954, income derived from patents has been taxed at the lower rate associated with capital gains rather than as ordinary income.

In addition, tax incentives for small businesses are frequently justified on the grounds that small businesses are particularly innovative, although there is little evidence to support such a generalization.

ERTA introduced several changes in the tax treatment of R&D:

- o R&D plant and equipment were placed in the shortest depreciation category, three years. As a result, they qualify for a 6 percent investment tax credit rather than the 10 percent available for investments given a longer asset life. As mentioned above, the combination of these factors appears to have produced a net disincentive for R&D investments under ERTA and a net incentive under TEFRA.

- o The incentives for donating equipment to universities were increased. Prior to ERTA, donating companies received a deduction equal to the equipment's original production cost. Companies can now deduct the production cost plus one-half the difference between production cost and the current market price so long as the total deduction does not exceed twice the production cost.

- o Treasury regulation 1.861-8, which required firms to charge a portion of R&D costs against foreign income, was suspended. This regulation, which was instituted in 1977, raised the effective tax rate of multinational firms and, some argued, encouraged the transfer of R&D to foreign countries. JCT estimates of Treasury losses as a result of this suspension were $55 million for fiscal year 1982, $120 million for fiscal year 1983, and $60 million for fiscal year 1984. Thereafter, its expected effects are minimal.

- o An incremental R&D tax credit was instituted.

The most important of these measures is the incremental R&D tax credit, which amounts to 25 percent of "qualified" R&D expenditures in excess of expenditures in a preceding base period. Qualified expenditures were defined as in the expensing option of Section 174--that is, capital expenditures were excluded. Base-period expenditures were defined on a company-specific basis, and the base period itself varied from the last six months of 1980 for expenditures in 1981 (when only R&D expenditures after June 30 could qualify for the credit) to an average of the preceding three years for expenditures in 1983 to 1985, after which the incentive is scheduled to expire. The 25 percent credit for incremental R&D expenditures is also subject to a cap; base-period expenditures can never be below 50 percent of the qualified expenditures for the year for which the deduction is claimed. Finally, 65 percent of R&D that is contracted out can be treated as qualified expenditures for the purpose of calculating the credit.

Because of its incremental character, the 25 percent tax credit for R&D is designed to be especially cost-effective, since it targets changes in firms' behavior. Whereas a nonincremental credit would reward firms for their existing level of R&D expenditures, an incremental credit encourages increased R&D funding, since only the increase over base qualifies for the credit. Such a program is not perfect, since it may reward firms that planned to increase their R&D expenditures even without the credit. Nevertheless, the incremental tax credit does represent an effort to encourage greater R&D activities in the private sector without causing significant revenue losses for the government.

The relevant issue in evaluating the incremental credit concerns the relationship between the revenue losses it generates and the additional R&D it encourages. The Joint Committee on Taxation has estimated that the revenue losses are roughly one-third those associated with the R&D expensing option (Section 174). The estimates for the incremental R&D tax credit are presented in Table 11, which shows some losses for years after the demise of the credit because of the overlap of fiscal and calendar years and the carryover of credits to 1987 and 1988. Estimates of the benefits of the incremental R&D credit--namely, the additional R&D it encourages--tend to be lower than the estimated Treasury losses. One study, for instance, suggests that the additional R&D generated by the incremental credit lies somewhere between $227 million and $638 million for 1983, compared to estimated Treasury losses of $645 million. In addition, some portion of the expenditures that qualify for the credit may represent a redistribution or redefinition of existing activities rather than additional R&D, further diluting the benefits of the program. Finally, analyses of similar tax incentives in other countries suggest the same result: tax credits for R&D

TABLE 11. ESTIMATED TAX REVENUES FOREGONE BECAUSE OF THE INCREMENTAL R&D TAX CREDIT (By fiscal year, in millions of current dollars)

Fiscal Year	Corporate	Individual	Total
1982	375	15	390
1983	615	30	645
1984	650	35	685
1985	660	40	700
1986	305	30	335
1987	65	5	70
1988	25	---	25

SOURCE: Joint Committee on Taxation estimates.

do not appear to be a particularly cost-effective mechanism for increasing R&D activity. 7/

Although the U.S. effects of an incremental R&D tax credit are not definitive, increased R&D does remain a policy goal, and extending the incremental R&D tax credit enjoys significant support. Its benefits may be diluted by the way its provisions interact, so that some reformulation of the

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7. These are the conclusions of a preliminary report funded by NSF. Edwin Mansfield, Public Policy Toward Industrial Innovation: An International Study of R and D Tax Credits (NSF, 1983).

39-373 O - 84 - 7

credit may be worth considering if it is to be extended. [8] Several features of the program are particularly significant in this regard, namely:

- The program provides a credit against tax liabilities;
- Expenditures are measured in nominal terms;
- The base period is varied;
- A cap is placed on the magnitude of the credit available for the full value of the deduction;
- Only certain expenditures qualify for the credit; and
- The credit is due to expire in 1985 (a sunset provision). [9]

Together these features may limit the effectiveness of the incremental tax credit in increasing R&D.

First, the credit can only be claimed if a firm has tax liabilities; for the large number of firms without tax liabilities, the potential credit provides no benefits. This is a particularly relevant point considering the depth of the 1981-1982 recession, when many firms were unable to use the credit. In fact, the provisions of the incentive may have a perverse effect on the R&D efforts of firms that have no tax liabilities, since under these circumstances increased R&D expenditures bring no credit but raise the base against which future expenditures are compared to calculate the increment. The potentially negative impact of this provision is offset to some extent by the fact that the credit can be carried over for 15 years, although its benefits diminish as the carry-over period increases.

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8. The following discussion is based largely on Eileen Collins, An Early Assessment of Three R&D Tax Incentives Provided by the Economic Recovery Tax Act of 1981 (NSF, April 1983), a summary of research funded by NSF; R. Eisner, S. Albert, and M. Sullivan, Tax Incentives and R&D Expenditures (Northwestern University, September 1983), the most recent product of the NSF research program; and J. Barth, J. Cordes, and G. Tassey, "The Recent Changes in Tax Policy on Innovation and R&D." See also Jane Gravelle, Congressional Research Service, "A Brief Assessment of S. 2165, The High Technology Research and Scientific Education Act of 1983," January 31, 1984.

9. The Senate Finance Committee has approved a bill making the R&D tax credit permanent, with some alterations in the definition of qualified expenditures.

Second, R&D expenditures are measured in current dollars for the purpose of determining the credit. Depending on the rate of inflation, an R&D tax credit could be earned regardless of whether real R&D expenditures were increasing, constant, or decreasing. Insofar as the intent of the law is to increase real R&D spending in the private sector, the use of nominal magnitudes in defining qualified expenditures could be misleading. To the extent that inflation naturally tends to raise the cost of carrying out a given level of R&D, this tends automatically to push firms toward the cap above which the incentives for increased R&D are diminished.

Third, the interaction between the calculation of the base period and the limit on increases in R&D spending that qualify for the full credit could produce perverse results. A firm that increases R&D spending by more than 100 percent would find that a dollar spent on R&D beyond the 100 percent limit effectively counts as 50 cents in terms of calculating the R&D credit, since the base increases automatically to ensure that the 100 percent limit is not exceeded. Thus the extra dollar beyond 100 percent would earn a credit of 12.5 percent rather than the full 25 percent. The law, however, does not correspondingly reduce the impact of expenditures above the 100 percent limit on the base with which expenditures in later years are compared. Under certain circumstances, the incentive to lower the base in order to boost future tax benefits might exceed the incentive to increase R&D spending in a given year. The net result would be that the interaction of these factors might tend to reduce R&D spending rather than to increase it.

Fourth, qualified expenditures are defined in the same terms as for Section 174--that is, only operating expenses, rather than capital costs, qualify for the credit. As currently implemented, the credit provides an incentive for firms to redefine other activities as R&D. Such behavior might lead to an increase in measured R&D expenditures without an equivalent increase in innovative activity.

Fifth, the sunset provision of the incremental tax incentive might shift spending toward 1985 at the expense of later years--presuming that firms expect the program to lapse. Currently, the chief effect of this provision is to eliminate by 1985 any consideration about the effect of 1985 expenditures on the base-period against which future tax credits will be calculated. In earlier years, the current tax benefits of increased R&D spending are offset to some extent by the fact that these expenditures raise the base for future years and thus lower the tax benefits generated by a given level of R&D spending. This base-period disincentive disappears in 1985, the final year of the program. Extending the incremental R&D tax incentive beyond 1985 would reintroduce this disincentive and thus tend to reduce R&D spending in 1985.

These considerations suggest that the incremental R&D tax credit is designed in such a way that its incentive effects are reduced, particularly by the interaction of the 100 percent cap and the method used to calculate base-period expenditures. The consequences of this credit can be summarized as follows:

- For most firms, the value of the credit will be less than 25 percent through most of the life of the program. Even for firms that do not exceed the 100 percent limit, the effect of increased R&D spending on the base serves to reduce the tax benefits available for a given level of R&D spending in future years. Nevertheless, the incremental R&D tax credit is a net incentive for most firms throughout the life of the program.

- As with any investment tax credit, the incremental R&D credit provides no incentives to firms that have no tax liabilities, either because of cyclical unprofitability or because they are new firms that are still developing their markets. For such firms, the program may actually provide a disincentive for R&D spending because of the potential advantages of reducing base-period expenditures. [10]

- Firms that are rapidly increasing their R&D expenditures may also find that the current incremental tax credit acts as a disincentive. This is because very large increases (exceeding 100 percent) do not qualify for the full incentive, since they automatically boost the base. At the same time, these expenditures have their full impact on the base for future years.

- The temporary character of the credit is likely to affect the timing of increases in R&D spending, with the maximum incentive occurring in 1985.

For most of the American economy, then, the incremental R&D tax credit does provide an incentive for increased R&D, although the incentive is likely to be less than the statutory limit. For firms in more extreme circumstances--those that have no tax liabilities in a given year and those that are rapidly increasing R&D spending--the impact of this program is limited or even negative. The number of firms that fall into categories for which the incremental tax credit may act as a disincentive is large; in one survey, for instance, 32 percent of total measured R&D expenditures in 1982

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10. Leasing of unused tax benefits to firms which can make use of them could alter this judgment.

were carried out by firms that paid no federal income taxes and could thus claim no credit. 11/ One would expect, however, that the impact of the credit would increase from 1983 to 1985, so long as the sunset provision remains in effect, since expenditures in later years have a diminishing (and by 1985 nonexistent) base-period effect and since economic recovery will bring more firms into the tax system.

Finally, the incremental R&D tax credit is not expected to have a significant effect on government revenues. The revenue losses associated with the long-standing expensing option (Section 174) are more than three times as great as the highest level of revenue losses resulting from the incremental credit (see Table 11). 12/

ANTITRUST POLICY

Traditionally, two conflicting perspectives have been presented to describe the link between antitrust regulations and innovation. Bigness appears conducive to innovation because it allows the diversification of risk and the realization of scale economies. These factors increase the prospects that innovating firms will be able to capture a larger share of the social return. On the other hand, competition is a spur to technological innovation in unregulated industries, and bigness may be associated with market concentration and therefore diminished incentives for innovation. No a priori basis exists for weighing the relative merits of these conflicting viewpoints. The evidence varies from industry to industry, often depending on the relative maturity of the technology involved. Regardless of the size of firms, however, it seems undeniable that rivalry over markets--whether among a few large firms or many small ones, whether among domestic firms or internationally--is a strong incentive to R&D and innovation.

With the increased importance of international competition to the U.S. economy, some reconsideration of the principles applied in antitrust cases may be in order, especially in regard to joint R&D activities. R&D joint ventures allow the firms within an industry to fund and carry out activities as a group that would allegedly be too expensive or too risky for individual firms to undertake. Such joint ventures are not expressly prohibited by the antitrust laws, and the Administration has indicated support for such

11. Eisner et al., "Tax Incentives and R&D Expenditures," p. 26.

12. Congressional Budget Office, Tax Expenditures: Budget Control Options and Five-Year Budget Projections for Fiscal Years 1983-1987 (November 1982), p. 52.

initiatives. Nevertheless, such joint projects remain a grey area in the law, and they are potentially subject to private antitrust suits under current laws. R&D joint ventures typically involve firms' commitments to contribute funds to a separate R&D entity to carry out research--particularly basic research--of general interest to their industry. Various arrangements are used. The R&D joint venture of the semiconductor industry, the Semiconductor Research Corporation, for example, typically funds university research. In the computer industry, the Microelectronics and Computer Technology Corporation plans to carry out much of its research in-house, using personnel assigned by the companies involved.

R&D joint ventures can also be linked with the venture-capital provisions of the tax system to create R&D limited partnerships, a device that is being heavily promoted by the Commerce Department. 13/ Such schemes rely on limited partners, who receive the favorable tax treatment given venture capital firms, to provide funding to an R&D enterprise that is set up by the firms likely to use the results provided by the research. This saves the eventual users the expense of carrying out the R&D, although they define the goals of the R&D effort and purchase any commercial results through licensing arrangements. In essence, such a device makes it possible for established firms in mature industries to tap the venture-capital market to fund their research. R&D limited partnerships are subject to the same antitrust considerations associated with R&D joint ventures, depending on the nature of the link between the user companies and the research enterprise.

Several bills relaxing antitrust restrictions for R&D joint ventures are now pending in the Congress. 14/ These bills typically include some safeguards against potential anticompetitive consequences. They also tend to ameliorate the potential penalties should an R&D joint venture violate the antitrust statutes; specifically, the treble damages normally levied in antitrust suits are reduced to single damages in cases involving R&D joint ventures.

Legislation may encourage the continued formation of R&D joint ventures, but the potential of this device is still unclear. Private firms are

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13. See R. Corrigan, "Administration Pushes R&D Pooling to Maintain U.S. Lead in High Tech," National Journal (October 1, 1983), pp. 1992-1996.

14. For a summary, see M. Wines, "The Administration, in High-Tech's Name, Takes Aim at Antitrust Laws," The National Journal (May 14, 1983), pp. 1000-1004.

understandably wary of the pendulum reversing itself on antitrust policy, especially since an R&D joint venture involves a long-term commitment. Even if pending legislation is passed, such ventures could be subject to private antitrust suits, although the incentives for such suits are reduced. Finally, and most importantly, it remains to be seen whether companies will be able to cooperate successfully in privately sponsored R&D. R&D joint ventures require firms to suppress their competitive instincts in that area and frequently to provide qualified scientific and technical personnel to the collective entity. Similar doubts apply to the financial potential of R&D limited partnerships. Whether such arrangements are viable is still an open question.

Regardless of the specific policy changes that are undertaken concerning antitrust, greater attention to technological issues in antitrust enforcement could play a role in encouraging innovation and R&D. This is especially true for interfirm cooperation in basic research. Fundamental trends in the American economy--especially the intensity of international competition--seem to justify a reexamination of antitrust activities. Some relaxation of antitrust strictures may be particularly appropriate for R&D, given the barriers limiting the R&D that an individual firm is likely to support and given the fact that government spending for civilian R&D is being cut back. Nevertheless, the importance of competition for fostering technological progressiveness cannot be overstressed.

PATENT POLICY

By granting patents, the government provides an innovator some monopoly status in order to preserve the incentives for invention. As is the case for the R&D effects of antitrust regulations, effective patent policy must balance two conflicting considerations. Inventions must be protected from imitation lest the reward to the innovator be undermined, but society also has a stake in the rapid diffusion of new processes and products, and patents may act as a barrier to such diffusion.

The U.S. patent laws provide for a patent lasting 17 years--an inevitably arbitrary period--from the time of filing. The duration of patent protection has rarely been discussed as a policy issue. The drug industry, however, has argued that the 17-year period should begin from the time new drugs are approved by the FDA, since government testing of such products can absorb a substantial portion of the period in which the patent can be enforced. The Senate has passed a law extending patent coverage by seven years in such cases, and a similar bill is pending in the House.

The most controversial area of patent policy concerns the patentability of inventions that are discovered by private researchers whose projects are funded, in whole or in part, by the government. Traditionally, the government has retained the patent rights to federally funded research. Some observers argue, on equity grounds, that if the general taxpayer funds R&D, private parties should not be able to appropriate the results without providing some compensation. The counterargument reflects the perspective that the economic and social benefits of government-funded R&D are maximized if the results of such activity are rapidly adopted and commercialized by private firms. If government retention of the rights to inventions it funds is an obstacle to the diffusion of new technologies, the overriding goals of technological progressiveness and economic growth argue for a more liberal policy stance.

Most studies of this issue have found that government retention of rights to the results of government-funded R&D has limited the commercial application of such results. 15/ The level of private licensing of government patents is quite low. Recognition of this fact led to 1980 legislation easing the cost of private use of government-funded inventions by small businesses and universities. Efforts to extend this treatment to large businesses have met some Congressional resistance.

Presidential action, however, may have rendered the issue moot. Last March, President Reagan instructed federal agencies to allow all businesses to retain rights to federally funded research, insofar as current law permitted this. This Presidential initiative may remove many of the obstacles that formerly confronted private firms seeking to patent the results of research funded by the government. Some safeguards have been maintained, however. An impact study must be conducted before private patent rights are granted, exceptions (especially for defense work) are provided for, and the government will retain so-called "march-in" rights (allowing it to retrieve patents transferred to private parties) if private firms are not vigorous enough in pursuing the commercialization of R&D funded by the government.

PROCUREMENT POLICIES

The federal government purchases a wide variety of commodities. By advertising its interest in certain products and by specifying the product

15. See Howard Bremer, "Patent Policies for Government-Sponsored Research (USA)" and Carole Ganz, "United States Patent Policies for Government-Supported Research" in A. Gerstenfeld, ed., Science Policy Perspectives: USA-Japan (New York: Academic Press, 1982).

characteristics it seeks, the government could elicit and shape private R&D activities without significant increases in the federal budget. This suggests that government procurement could be used to influence the pattern and pace of innovation and technical advance. Government procurement clearly plays a significant role in shaping innovation in defense and related (for example, aerospace) industries. DoD demand for semiconductors, for instance, played a crucial role in attracting investment during the early growth of what is now primarily a nondefense industry. This model has attracted interest in the potential of government procurement to influence technology and R&D outside the defense sector.

Government purchases can provide a large and stable market, thus reducing the risks of committing R&D funds to innovative projects. Coordinating government procurement and incorporating technological concerns into procurement decisions could encourage private-sector R&D activities in civilian as well as defense sectors. Nevertheless, there is little evidence that procurement could play a major role in boosting the technological performance of civilian industries. Despite large purchases of vehicles, office equipment, and so on, the government will never dominate the market for such products, as it does in defense areas. Moreover, one should not underestimate the difficulty of reshaping the procedures and priorities that now determine federal procurement outside defense. Insofar as technological considerations could be introduced into government procurement decisions, this could encourage more rapid innovation in the private sector. Nevertheless, procurement policies are unlikely to be more than a complement to specific R&D policies in the other areas discussed in this report. 16/

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16. See the discussion in Richard Nelson, "Government Stimulus of Technological Progress: Lessons from American History," in Richard Nelson, ed., Government and Technical Progress; A Cross-Industry Analysis (New York: Pergamon Press, 1982).

CHAPTER VI. IMPROVING FEDERAL SUPPORT FOR R&D AND INNOVATION

A variety of approaches have been proposed to improve federal support for R&D and innovation. These include changes in the pattern of federal financial support, relaxed antitrust enforcement for joint R&D ventures, the extension of R&D tax benefits, the use of R&D limited partnerships to tap the pool of venture capital, and government encouragement of closer relations between industry and academia. Some policymakers have also called for more fundamental institutional reforms, including the establishment of technology utilization centers or a National Technology Foundation.

Policymakers' attitudes toward these proposals largely depend on their conception of the federal role in innovation. Unless this underlying issue is explicitly addressed, specific programs are likely to be less effective than they could be. This chapter begins with a discussion of alternative views of the federal role and then turns to different options for implementing them.

WHAT ROLE FOR GOVERNMENT?

The government's role in R&D and innovation can be discussed on several levels:

- First, the government has a relatively clear responsibility for funding the R&D that is needed to provide public goods such as defense. In such cases, the government is the sole or prime purchaser of the technology and defines the product requirements that must be met.

- Second, the government funds university-based research. This has several justifications: the cultural value of science, national prestige, educational support, and the maintenance of the scientific pool that is the ultimate source of innovation.

- Third, the government pursues a variety of social and economic goals, most of which can be identified with the mission of a particular government agency. Insofar as new technologies can help fulfill these agencies' missions, the government typically provides some funding for related R&D.

- Finally, the government has some responsibility for the overall technological performance of the economy. At the very least, this involves maintaining a supportive macroeconomic environment. It may also involve more active government intervention, for example, funding industrial R&D, providing private firms with information concerning technical developments, acting as a broker between industry and academia, and so on.

There is little dispute about the first two areas of governmental responsibility, although the level and composition of such funding can be controversial. The most difficult issues in innovation policy concern the government's role in supporting mission-oriented civilian R&D through agency budgets and in supporting innovation in the economy as a whole. Succinctly stated, this issue revolves around where one defines the boundary between public responsibility and private initiative. If the government funds R&D that might otherwise be carried out by the private sector, this squanders government revenues and may misdirect technical resources. This danger is particularly relevant to mission-oriented R&D, such as the funding that has been provided for energy technologies since the energy crisis. At the same time, however, there is widespread agreement that the private sector will underinvest in certain types of research, suggesting that the economy's technological performance could be significantly diminished if the government defines its responsibilities too narrowly.

One's definition of the government's responsibilities for the overall technological performance of the economy depends on one's view of the innovation process and the role of R&D in that process. The model underlying U.S. innovation policy since World War II has been referred to in this report as the pipeline concept. In practice, this view of the innovation process tends to limit the governmental role to support for basic research, although the urgency of other social goals, such as energy independence, has frequently led to substantial federal support for civilian development. According to the pipeline view, the private sector can be relied upon to use the knowledge developed through basic research when market conditions are ripe. While the pipeline concept does not rule out government support for practically oriented research or government efforts to promote new technologies (the kinds of activities carried out by the Agricultural Research Service, for instance), neither has it endorsed government responsibility in such areas. As a result, the pipeline concept offers little guidance concerning the government's role in regard to activities that are more practical than basic research but less commercial than development. Such activities are generally referred to as applied research; the related concept of "generic technology" is used to denote a technology, such as improved welding techniques, that is likely to find applications across several industries. This type of research is clearly of more immediate interest to private businesses than is basic research, yet it shares with basic research many of the characteristics that are cited to justify federal support.

During the past 15 years, a variety of programs have been developed to deal with the kinds of general innovation issues that are left unaddressed by the pipeline view: how deeply should the government be involved in applied research, what are the industry-specific consequences of governmental innovation policies, how active should the government be in promoting business innovation, and so on. Some of these programs are listed below:

- The Research Applied to National Needs (RANN) program was established during the Nixon Administration to target NSF projects to explicit national goals, mainly of a noncommercial nature (for example, earthquake research).
- The New Technology Opportunities Program (NTOP), also a product of the Nixon Administration, called for a comprehensive government effort to accelerate innovation. NTOP originally included tax incentives, greater funding for applied civilian research, changes in antitrust enforcement, and institutional reforms. This program was never fully implemented, however.
- The Experimental Technology Incentives Program (ETIP), first implemented during the Ford Administration, was designed to influence government agencies to be more conscious of the impact their policies (regulation, procurement, and so forth) might have on innovation.
- Centers of Generic Technology (COGENT) were established by the Stevenson-Wydler Technology Innovation Act of 1980. These centers, operated through the Commerce Department, were designed to identify promising generic technologies that were underfunded and to match private funding for R&D in such technologies. The centers were planned to be self-supporting (through the sale of patents and licenses, for instance) after an undefined period.

This is not an exhaustive list. 1/ Nevertheless, it indicates the bipartisan history of recent government efforts to influence the overall pace

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1. For a discussion of such programs, see H. Fusfeld, R. Langlois, and R. Nelson, The Changing Tide: Federal Support of Civilian-Sector R&D (New York: New York University School of Business Administration, November 1, 1981).

of innovation through programs that go beyond basic research funding. The current Administration has generally sought to reverse the trend toward greater government involvement in commercial R&D. The pipeline view has been invoked to justify the restriction of government funding to basic research, and government activities in nontraditional areas have been severely reduced in the Administrations' budget requests. The COGENT program, for instance, was halted before it had really begun, and real civilian development spending has been cut to one-third the 1980 level. The predominance of defense in federal R&D budgets is being reestablished. The Administration now supports increases in civilian basic-research funding on the grounds that such activities are ". . . key to . . . the long-term competitiveness of the U.S. economy . . ." 2/ Certainly, such research advances scientific frontiers. But there is little evidence that government-funded civilian basic research generates commercial products and processes that enhance the competitiveness of American industries. Indeed, some have argued that increased U.S. basic research may enhance the competitiveness of other countries, such as Japan, that may be more adept at transforming scientific findings into products.

The withdrawal of government funding from commercially oriented R&D need not weaken the technological performance of the economy--so long as the private sector provides adequate support to applied research and development. The Administration has linked its commitment to basic research with increased incentives for private R&D activities, for example, the incremental R&D tax credit. In addition, it has sought to encourage R&D joint ventures and limited partnerships, which may remove some of the barriers to private support for long-term research. The Administration has also expressed its support for encouraging greater cooperation between industry and the basic-research community, especially at universities. 3/

Current policy therefore reflects a relatively clear view of the innovation process and the government's role in it, namely, reliance on the private sector for activities other than basic research. In practice, current policy accepts little government responsibility for altering the mix of private-sector R&D, shaping innovation policies according to the needs of specific industries, or generally supporting applied commercial research. Policymakers who do not share the Administration's views support innova-

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2. Budget of the United States Government, Fiscal Year 1984, "Special Analysis," p. K-2.

3. See, for instance, G. Keyworth, "Federal R&D and Industrial Policy," Science, vol. 220 (June 10, 1983), p. 1122-25.

tion policies that focus more explicitly on the linkages between basic research and the technological performance of the American economy. How to resolve this difference in perspective is the most critical issue facing innovation policy.

POLICY OPTIONS

A wide variety of government policies, not all of which have been discussed in this report, affect the economy's technological performance. The remainder of this chapter presents proposals for improving the government's R&D and innovation policies in four broad areas: R&D funding, taxation, regulation, and institutional arrangements.

Funding

Several measures could be considered to increase the effectiveness of the large sums the government now spends on R&D. Improved technological performance in the economy as a whole is not necessarily contingent on large additional R&D expenditures. Improvements in the efficiency with which government R&D funds are used could be gained by placing more emphasis on such issues as the reliability and mix of funding.

Stability of Funding. Attention is often paid to the aggregate level of R&D allocations, especially in terms of R&D spending as a percent of GNP. There is no basis for defining an optimum level of R&D spending in such terms, however. The stability and mix of funding are at least as important, and they are particularly worthy of attention in a period of increasing budgetary constraints. Research projects are inherently long-lasting, with no immediate payback. As a result, volatile funding levels--even if they generate a secular increase--are highly disruptive of research. This point has long been recognized; it was the first of the "five fundamentals" that were proposed as the basis for federal science policy in Vannevar Bush's Science: The Endless Frontier, the World War II blueprint for postwar R&D activities. 4/ Nevertheless, this principle is frequently ignored, as was the case in the Administration's first budget proposals.

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4. Vannevar Bush, Science: The Endless Frontier; A Report to the President on a Program for Postwar Scientific Research (New York: Arno Press, 1980), p. 33. This work was originally published as a government report in 1945. The other four of the "five fundamentals" were the control of science policy by qualified personnel, the grant system, the peer-review system, and ultimate accountability to the President and the Congress.

Current R&D budgets show a strong growth trend for basic research, and Administration statements suggest that this commitment will persist. Nevertheless, even stable aggregates can mask volatile patterns of spending in specific technologies or sciences. The continuity of funding should therefore be evaluated on a fairly disaggregated level. The increased efficiency that is likely to be associated with long-term stability in R&D funding suggests that policymakers might wish to consider defining disaggregated R&D budget allocations on a longer-term basis, for example, using two-year appropriations.

The Mix of Funding (Basic, Applied, Development). The mix of federal R&D funding can be evaluated along several dimensions, the most common of which involves the distinctions among basic research, applied research, and development. As mentioned in Chapter IV, current trends in R&D spending raise questions about the adequacy of federal support for applied research. It is in this category that the overall pressures on the budget are felt in terms of R&D funding, since applied makes up a relatively small (and declining) part of the defense budget and since it generally falls outside the Administration's demarcation of the acceptable terrain for governmental support of civilian R&D.

The Congress may wish to consider this policy issue, especially insofar as economic performance is the principal reason for Congressional interest in R&D. The long-term, noncommercial character of basic research suggests that increased spending on basic research will contribute little to improved economic performance through the rest of this decade. More ominously, while increases in basic research will raise the level of American science, there is no guarantee whatsoever that this will boost the competitiveness of American industry. Scientific advances are rarely restrained by national boundaries. Furthermore, the border between applied research and basic research may have little to do with the division between activities which the market will and will not support. If federal R&D spending seeks to foster innovation and thus improve economic performance, applied research, which links the laboratory and the production line, may be the activity most deserving of support. This issue is clearly tied to how one defines the appropriate governmental role in encouraging innovation.

The rationale for federal funding of civilian development projects is much more dubious, and funding for such projects has been cut substantially in recent years. Development activities are generally far more expensive than research, so that reduced development funding could lower government expenditures as well as free resources for research, both basic and applied. If private investors are unwilling to fund a development project, this may indicate that the technology involved has poor commercial prospects.

R&D Support for Industry. Current patterns of federal R&D funding by industry reflect the paradigm that underlies government R&D activities. Government funding is heavily skewed towards defense industries and other industries that provide public goods. Although the causal linkage is unclear, government R&D funding by industry seems correlated with the sectoral pattern of international competitiveness. Increased government funding of research (both basic and applied) relevant to nondefense industries--particularly those basic industries that are hard-pressed by international competition--could restore some measure of neutrality to the sectoral targeting inherent in current R&D funding. Such government expenditures could be reduced by linking federal funding to some sort of matching funding by industry. Provided incentives were maintained for private parties (through government waiver of patent rights, for instance), such a matching principle would increase the likelihood that government funding would lead to commercial applications as rapidly as possible.

In addition, the current emphasis on defense raises the question of whether R&D resources, particularly skilled personnel, are being diverted from civilian R&D. Should this be the case, the current pattern of R&D spending may undermine the competitiveness of American industries until the supply of scientists and engineers increases--a development that is likely to require several years. Spending for civilian technologies should be considered against this background. Policies in areas such as education could be used to increase the supply of qualified scientists and engineers for both the civilian and defense sectors.

Funding for Science. As the costs of basic research increase, especially in areas such as particle physics and space exploration, greater efforts could be made to reduce costs through international cooperation. The unit cost for the next generation of particle accelerators, for instance, is currently estimated at between $2 billion and $3 billion. 5/ Funding for international scientific projects has been reduced by the current Administration, and policymakers often have an understandable tendency to view science as an international competition that the United States should seek to win. Such an effort would prove extremely expensive, however, and it would mean little in terms of the economic competitiveness of American industries. Greater commitment to international scientific efforts could expand the pool of knowledge from which innovations are drawn, reducing expenditures by the U.S. government and increasing the prospects for worldwide economic growth. Provided U.S. industry is an aggressive adopter

5. See W. J. Broad, "Physicists Compete for the Biggest Project of All," The New York Times, September 20, 1983, page C-1.

39-373 O - 84 - 8

of new techniques, greater international cooperation in basic science need have no negative effect on U.S. economic performance.

Taxation

Tax policies are a significant policy tool influencing overall private R&D expenditures. Nevertheless, it is extremely difficult to track the impact of tax policies on private decisions, since tax rates are only one of the factors that shape those decisions. If private R&D expenditures rise following the enactment of an R&D tax incentive, this may imply a causal relationship. One does not know the quantitative impact of such an incentive, however; expenditures might have risen anyway because of other factors (competitive pressures, macroeconomic conditions, and so forth). Abstracting from the impact of nontax conditions, changes in the tax code affect economic behavior by altering the structure of relative incentives.

Despite the inclusion of specific R&D incentives in recent changes in the tax laws, the overall impact of these changes on R&D activities per se does not seem to be large. (Indirect benefits in innovation, induced by increased demand for capital equipment and the diffusion of new technologies, are likely to be more substantial.) If the Congress wishes to use the tax system to shift resources toward R&D, stronger measures could be considered. Full expensing of R&D costs (that is, extending the expensing option to plant and equipment as well as to labor and materials) is one such measure, although this might encounter problems in allocating expenditures for plant and equipment that are used for several purposes, only one of which is R&D. An increase in the R&D investment tax credit (ITC) from the current 6 percent is another option. Refundability of the ITC and/or the incremental tax credit would ensure that even less profitable firms (for instance, start-up companies establishing their markets) would obtain the full value of the credit without having to carry over the credit to future years. Such measures would, of course, be more costly than current policy, but they would also be more likely to make a direct difference in private firms' commitment to R&D than do most ERTA/TEFRA reforms.

Changes in the structure of the incremental tax credit, which is due to expire at the end of 1985, could increase the incentive effects of that program. Such changes might include the following measures:

- o Increase the amount of the credit, currently 25 percent.

- o Attempt to calculate the base in real terms, ensuring that inflation does not dissipate the incentive effects of the credit.

- o Eliminate the cap on chargeable increases. Alternatively, the disincentive effects of the cap could be reduced by not counting expenditures in excess of the cap in the base period for later years.

- o Calculate the base expenditure on an industry-specific rather than company-specific basis.

- o Tighten the definition of qualified expenditures to increase the likelihood that the funding increases claimed under the credit represent actual increases in R&D.

- o Finally, extend the credit beyond 1985. As presently formulated, however, the sunset provision reduces the disincentives associated with the calculation of the base for 1984 and 1985. Extension of this incentive should therefore be considered in conjunction with refinements such as those mentioned above.

In general, the incentives for increased R&D provided by recent changes in the tax system appear to be relatively minor. Given the fact that current spending policies rely heavily on the private sector to fill in the gap left by the withdrawal of federal funding from civilian applied research and development, policymakers might consider strengthening the incentives for private R&D. At the same time, studies of the costs and benefits of R&D tax incentives raise doubts about the efficiency of this approach, although more investigation of this issue is needed. These studies do suggest, however, that targeted programs designed to boost private commitment to basic and applied research--activities that are more vulnerable to market failures than is development--might be especially worthy of consideration.

Regulations

Regulatory policies, particularly in the antitrust area, could play a significant role in removing some of the barriers to private R&D activities, particularly in less commercial research. As with tax policies, altered regulatory policies might be particularly important in terms of potentially offsetting reduced government funding of civilian R&D. Relaxed antitrust restrictions for R&D joint ventures (including tax-based limited partnerships) are currently attracting Congressional interest as well as Administration support. So long as competitive pressures are maintained, joint ventures could be a potent means for carrying out the sort of fundamental research that is frequently unattractive for individual firms. Moreover, such institutions increase the likelihood that research results would be rapidly transformed into commercial products and processes, since private firms would be involved from the inception of research projects. These arguments underlie the various legislative proposals that remove some of the antitrust barriers to R&D joint ventures.

Enthusiasm for relaxing antitrust enforcement could be carried too far, however. The spur of competition is almost a prerequisite for innovative activity. Changes in antitrust enforcement should be carefully evaluated, therefore, to determine their effects on competition, effects that are likely to vary by industry.

In other areas of regulatory policy, the Congress could act to ensure that technological impact is considered when regulations are being formulated. For instance, if environmental policies might draw R&D resources away from productivity-enhancing activities in a given industry, some effort could be made to mitigate this effect or to offset it through spending or tax policies. The Experimental Technology Incentives Program (ETIP) was designed to monitor and influence such relationships.

Finally, the Congress could consider supporting the Administration's efforts to grant patent rights to the firms that perform government-sponsored R&D. Evidence suggests that government retention of rights serves to retard innovation rather than to increase government revenues.

Institutional Arrangements

Insofar as the government assumes some responsibility for the overall technological performance of the economy, it might be worthwhile to evaluate new institutional arrangements for devising and implementing innovation policy. Policies based on a more active government role in facilitating improved technological performance should have some institutional foundation. Although the Administration is generally opposed to governmental activism in regard to commercially oriented activities, it has proposed some limited institutional improvements. The Administration's enthusiasm for R&D joint ventures represents support for new private institutions. In addition, the Administration has sought to foster university-industry cooperation; this was the rationale used to justify the proposed National Materials Laboratory at Berkeley. The Congress did not fund this project fully, however, because it had not undergone the conventional review process and because it provoked strong resistance from materials scientists--even those who support closer relations between science and industry--who deemed the program ill-conceived. 6/ The Congress did provide funding for a technical review of this project, however.

Several arguments could be cited to justify stronger institutional initiatives than those favored by the Administration. First, an institutional apparatus might be needed to tailor the government's innovation policies to the industry-specific factors that affect technological performance. Second, an institution charged with fostering innovation in the economy as a whole could ensure that government funding is available for applied research projects that are likely to be underfunded by the private sector, supplementing the basic research funded by NSF, NIH, the DoD, and other agencies. Finally, an institution whose primary mission concerns technological performance could be a source of expertise for private firms and for other government agencies, making the technological implications of government policies more transparent.

Such arguments find their strongest expression in calls for a "National Technology Foundation," akin to NSF. Such a foundation has been proposed for several years, especially by the engineering community. Its proponents argue that science and technology represent related but distinct activities. In the past, the responsibility for overseeing government activities in both areas--at least as far as the civilian economy is concerned--has devolved primarily on NSF. Yet NSF serves the university community, which is primarily interested in basic research. Because of this, efforts to implement more commercial applications have little institutional support within NSF. In recent years, the Commerce Department has also assumed greater responsibility for fostering technology. Here as well, however, technological performance is not the primary concern of the department. Proponents of a National Technology Foundation argue that the policy goal of improved technological performance is important enough to warrant an independent institution.

Most proposals for a National Technology Foundation (NTF) call for an institution drawing on existing governmental operations: the National Bureau of Standards, the NSF's engineering programs, the Patent and Trademark Office, and some Commerce Department activities. One exam-

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6. See G. Keyworth, "Federal R&D and Industrial Policy," p. 142; and A. Robinson, "Berkeley Advanced Materials Center OK'd," Science, vol. 220 (February 18, 1983), pp. 827-28. On the general issue of government encouragement of university-industry cooperation, see the recent report by the Government Accounting Office, The Federal Role in Fostering University-Industry Cooperation, GAO/PAD-83-22 (1983).

ple of such a foundation is described in the National Technology Foundation Act of 1983 (H. R. 481), introduced by Congressman Brown of California.

Advocates of a separate technology foundation must confront several criticisms, even granting the underlying point that the government should play a more active role in the applied research area. First, the establishment of a new agency would represent a major policy initiative, a step that might lead to large additional outlays. Second, there is no guarantee that an NTF would prove significantly more adept at supporting civilian technologies than the current institutional structure of federal R&D support. Third, it could be argued that the institutional separation of basic from applied research would be counterproductive, in effect introducing a crack in the pipeline. This consideration argues for linking technology support more closely to NSF and other government agencies, such as NIH and DoD, that fund basic research. Finally, it is not clear that industry--which is the key player in the innovation process--is enthusiastic about a National Technology Foundation.

Another proposal, the Advanced Technology Foundation Act (H. R. 4361), introduced by Congressman LaFalce, also calls for the establishment of a new agency, in this case an Advanced Technology Foundation. This foundation would be empowered to provide grants and loan guarantees to research organizations for carrying out applied research, particularly in generic technologies. In addition, it would foster the diffusion of new technologies and collect information on the technological status of different industries. Finally, the foundation would establish an Industrial Extension Service, modeled after the Agricultural Extension Service and designed to provide private manufacturers with technological support.

Policymakers could also consider institutional initiatives that entail greater governmental activism than do the Administration's proposals but fall short of a National Technology Foundation. The Manufacturing Science and Technology Research and Development Act (S. 1286 and H. R. 4155), introduced by Senator Gorton and Representative Fuqua, is one such proposal. Rather than establish a separate technology agency, this bill would direct the Secretary of Commerce to support research in key manufacturing technologies by funding basic research in such areas and by matching private funding for more applied research at so-called "Centers for Manufacturing Research and Technology Utilization." In addition, the bill calls for combining R&D in advanced manufacturing technologies with worker retraining and for investigating the long-term competitive implications of technological performance in key industries.

Each of these bills calls for the establishment of new institutions to assist private firms to develop and apply new technologies. Moreover, these institutions are designed to do more than fund applied or generic research; they also focus on information gathering and dissemination and advisory activities. Such institutional solutions reflect the view--contrary to current policy--that the government's responsibility for the economy's overall technological performance extends beyond the provision of funds for basic research and the establishment of incentives for private-sector activities.

APPENDIX

APPENDIX A. R&D INTENSITY AND INTERNATIONAL COMPETITIVENESS: METHODOLOGY

Table 3 in Chapter III presents estimates of product-specific, direct R&D intensity ratios and of the U. S. share of total exports by product class by members of the Organization for Economic Cooperation and Development.

R&D intensity estimates are based on average values for 1968 and 1970 and for 1977 and 1979, respectively. R&D expenditures were taken from National Science Foundation data on "Applied R&D Expenditures by Product Field." The U.S. Bureau of the Census also uses these product categories in The Annual Survey of Manufactures, which is the source for data concerning the value added by product class. As used in Table 3, direct R&D intensity is the ratio of R&D expenditures over the value added for each product area.

To obtain the U.S. percentage share of exports by the same product classes, it was necessary to translate the U.S. SIC codes into the International Standard Industrial Trade Classification (SITC) codes produced by the United Nations. For 1971, this translation process used the key provided by Regina Kelly. 1/ In 1978, however, these codes were updated and it was therefore necessary to redo the translation for 1980 exports. Table A-1 provides the key that was used for that year, based on CBO estimates.

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1. Regina Kelly, The Impact of Technological Innovation on International Trade Patterns, U.S. Department of Commerce (1977).

TABLE A-1. PRODUCT FIELD CATEGORIES, U. S. SIC CODES AND SITC CODES: 1980

Product Field	SIC Code	SITC Code
Textile Mill Products	22	65 (-658)
Chemicals (except drugs and medicines)	28 (-283)	5
Industrial organic and inorganic chemicals	281, 286	51, 52, 531, 532 551, 533
Agricultural chemicals	287	56, 591
Plastic materials and synthetics	282	58
Drugs and Medicines	283	54
Rubber and Miscellaneous Plastic Products	30	62, 893
Stone, Clay, and Glass Products	32	66 (-667)
Ferrous Metals and Products	331-32, 3398-99	67, 333
Nonferrous Metals and Products	333-36	68
Fabricated Metal Products	34 (-348)	69, 711, 81
Machinery	35	
Engines and turbines	351	712, 713, 714, 716, 718
Farm machinery and equipment	352	721, 722
Construction mining and materials handling machinery	353	723, 728, 744, 782
Metalworking machinery and equipment	354	73

(Continued)

TABLE A-1. (Continued)

Product Field	SIC Code	SITC Code
Office, computing, and accounting machines	357	75
Electrical Equipment except Communication	36 (-365-37), 3825	
Electric transmission and distribution equipment	361, 3825, 362	773, 771
Other electrical equipment and supplies	363-64, 369	775, 778, 774
Radio TV Receiving Equipment, Communication Equipment, and Electronic Components	365-67	76, 772, 776
Motor Vehicles and Equipment	371	781
Other Transportation Equipment	373-75, 379	791, 78 (-782, 781) 793
Aircraft and Parts	372	792
Professional, Scientific, and Measuring Equipment, including Optical, Medical, Photographic, and Chronometric	38 (-3825)	87, 88