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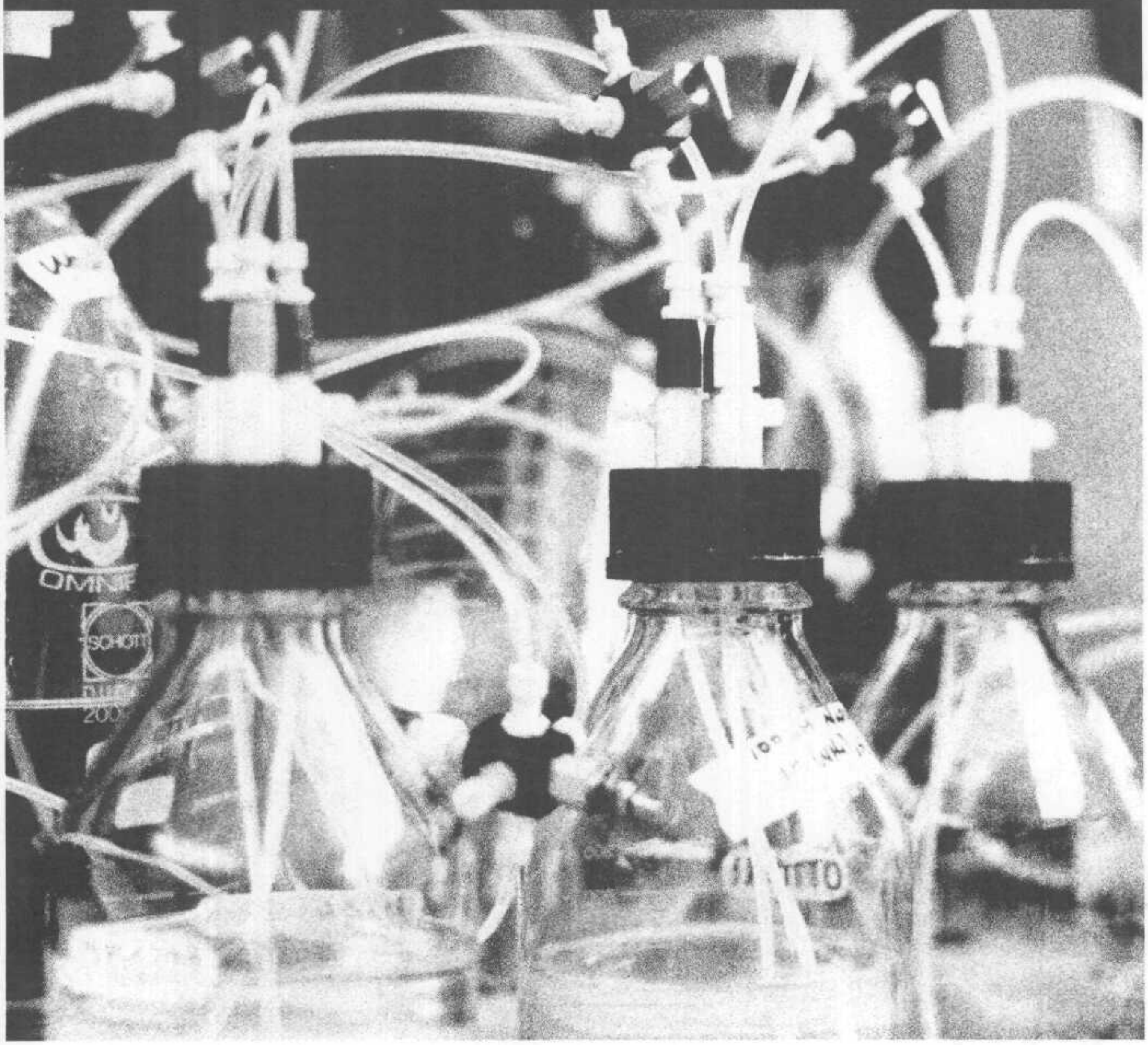
Using Federal R&D to Promote Commercial Innovation



A SPECIAL STUDY

USING FEDERAL R&D TO PROMOTE COMMERCIAL INNOVATION

The Congress of the United States
Congresssional Budget Office

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PREFACE

Developing new products and new production processes enhances the ability of manufacturers to compete in international markets. This study considers how the federal government supports research and development and how this support has affected commercial innovation in the United States. It also discusses options the Congress might consider to stimulate more such innovation by the private sector. The report was prepared at the request of the Senate Budget Committee. In keeping with the mandate of the Congressional Budget Office to provide objective analysis, the report makes no recommendations.

Daniel P. Kaplan of CBO's Natural Resources and Commerce Division wrote the report under the supervision of Everett M. Ehrlich and Elliot Schwartz. Colleen Loughlin, Lisa Najarian, and Meredith Wolff made valuable contributions. Victoria Farrell, Marilyn Flowers, Stephen Miller, and Philip Webre of CBO made a number of useful suggestions. Carol Kitti and Gregory Tassey also provided helpful comments. Paul L. Houts edited the manuscript. Margaret Cromartie typed the many drafts, and Kathryn Quattrone prepared the report for publication.

James L. Blum
Acting Director

April 1988

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SUMMARY

Rising trade deficits in the 1980s have led many people to doubt the ability of U.S. manufacturers to compete in world markets. Anecdotal evidence about the decline in the quality of domestic products tends to support these qualms. Yet, there is little evidence to suggest that domestic firms suddenly and dramatically became less efficient than their foreign rivals in recent years. Instead, any difficulties that domestic manufacturers have had competing in world markets stem chiefly from the strength of the dollar in foreign exchange markets at the beginning of the decade.

The fall in the value of the dollar will ultimately narrow the trade deficit. A lower dollar reduces the prices to foreigners of U.S. exports and helps those employed in export industries. But the combination of more exports and fewer imports may reduce the amount that U.S. citizens have to consume and invest, and thereby reduce their standard of living. Thus, a depreciating dollar can reduce the nation's economic well-being at the same time that it corrects the trade balance; this double-edged effect is the essence of the "competitiveness" problem.

In response to the perceived decline in the competitiveness of domestic industry, some have urged the Congress to take steps to increase the innovativeness of domestic industry. New production technologies--process innovations--generally increase the productivity of U.S. manufacturers, and they allow the United States to produce more from its limited resources. In addition, domestic firms are generally able to price new products--product innovations--above their manufacturing costs in world markets. Foreign sales of these product innovations would thereby increase the value of exports without a corresponding increase in the quantity of domestic resources used to produce them.

Increasing the innovativeness of domestic industry would make the United States more competitive. But even if the Congress established programs that successfully stimulated the development of new commercial products and processes, these programs would have little

near-term impact on the trade deficit, which is largely a macroeconomic phenomenon. Consequently, decisions to change the government's role in the nation's innovative efforts should be based on an analysis of the expected long-run effects.

GOVERNMENT R&D POLICIES

The federal government funds much of the nation's research and development, and R&D is a major factor in the development of innovations. In fact, federal support of R&D has been instrumental in the evolution of a number of the nation's most technologically advanced industries. Nevertheless, encouraging commercial innovations has never been a principal objective of federal R&D. Instead, the Congress has largely directed government efforts toward activities that the private sector has limited incentives to perform.

Direct Support

The government currently funds nearly half of the nation's research and development. This share fell continuously between the mid-1960s and the late 1970s as government expenditures, in real terms, fell and industry expenditures rose. With the defense buildup of the 1980s, the government's share of the nation's expenditures for R&D has resumed its growth.

Procurement. By far the largest area of government support for R&D involves government procurement. In areas such as defense and space, the government's product needs are unique and, for all practical purposes, the government is the only potential customer. In recent years, defense has accounted for two-thirds of the government's R&D expenditures, and the bulk of these funds were devoted to developing new weapons systems for the Department of Defense.

Basic Research. The government is also a major supporter of research that has no immediate practical or commercial applications. Such basic research does, however, expand the stock of knowledge and helps to form the base for future commercial innovations. The federal government funds nearly two-thirds of the nation's expenditures on basic research.

Firms tend to underinvest in R&D because of the problems of appropriability and of risk. These problems are likely to be the greatest in the case of basic research. First, although firms perform R&D to earn profits, an innovating firm cannot prevent others from appropriating--or benefiting from--its R&D. Moreover, because scientists frequently publish the results of their efforts, this problem of appropriability is greatest with basic research.

An investment in R&D also tends to be risky, especially in the case of projects attempting significant technological breakthroughs. A firm must normally overcome a host of obstacles--both technological and commercial--in translating a research discovery into an innovation. Firms can limit these risks by concentrating on activities that do not involve new technologies and that can be completed in a relatively short period of time. Thus, firms probably devote too many resources to developing simple modifications of existing products and not enough on more basic research. Moreover, U.S. firms, in contrast to the Japanese, spend a lot less of their R&D on process innovations than they do on product innovations.

Commercial Innovations. In a number of cases, however, the government has supported R&D aimed at developing commercial innovations. The most notable of these projects was the government's initiatives to develop nonpetroleum-based sources of fuel as well as conservation methods during the "energy crises" of the 1970s. These efforts achieved only limited success, and the Congress scaled them back early in the Reagan Administration. In one critical respect, the government's approach to creating new energy technologies and to creating new weapons systems were quite similar--the primary goal of the effort was developing a new technology. In contrast, firms engage in R&D to earn profits, and they receive little value from a new product or process if the innovation cannot be used commercially.

Helping Industry. Recently, several programs have been established whose primary aim is to provide direct aid to firms in the private sector. For example, in the cases of the Engineering Research Centers (established by the National Science Foundation at various universities to perform generic research) and Sematech (a consortium seeking new manufacturing techniques for semiconductors), the government and private firms have established and jointly funded research centers. A central goal of these centers is to help domestic firms become more efficient, and firms play an important role in determining the direction of the research at these centers. Since numerous firms participate in each center, the research often strives for broad applications, such as general know-how and some kinds of process innovations. Firms generally want to maintain exclusive control of more specialized innovations--new products, for example--and therefore develop them in a proprietary setting.

Indirect Support

The Congress has also provided indirect support of innovative activity. In 1981, for example, it adopted an R&D investment tax credit that benefited firms that increased their expenditures on research and development. The Congress has also taken steps to make the technologies resulting from government-supported research more accessible to the private sector. These steps have included modifications in the way that the government licenses technologies developed with government funds as well as better dissemination of research results.

STIMULATING INNOVATIVENESS IN THE PRIVATE SECTOR

Although the creation of commercial innovations has never been central to the government's support of R&D, government R&D has, nevertheless, played a major role in a number of commercial markets.

The nature of technology developed is the most important determinant of whether government-sponsored R&D will yield commercial spillovers. Yet, a technology must also be applied successfully. A number of features are associated with the successful commercialization of government-supported research:

- o Potential users know about the relevant research;
- o Researchers trying to apply the new technology can effectively communicate with those performing the research;
- o Firms make the ultimate decision about introducing an innovation and bear substantial financial risk; and
- o The program encourages private sector R&D--in other words, the government does not finance research that would have been performed in any event.

THE PROS AND CONS OF ADDITIONAL SUPPORT

A number of reasons justify further government encouragement of private sector innovativeness. In the first place, it could increase the nation's competitiveness. Despite the greater competition from foreign firms, the proportion of GNP devoted to research and development in the United States is lower now than it was 20 years ago. In addition, the government--and most notably the military--has consistently played a critical role in the innovative efforts of the private sector. But the commercial impact of the military's current programs seems unlikely to be as large as some of its earlier efforts.

On the other hand, despite the importance of research and development to the nation's competitiveness, further government assistance might not be appropriate for a number of reasons. To begin, the government has little experience in making commercial decisions; consequently, its efforts may lead to a misallocation of resources. Moreover, even if the federal government successfully stimulated new technologies, the advantage to the United States might be transitory. A domestic firm may decide to use the innovation in another country, or a foreign firm may be able to copy it quickly. Finally, private firms are responding to the greater competitive challenges in a variety of ways, one of which has been to increase R&D expenditures. Consequently, the Congress may have more success in improving industry competitiveness by other means. These might include programs to increase savings and investment or to improve educational quality.

WAYS TO INCREASE SUPPORT OF PRIVATE SECTOR INNOVATIVENESS

The Congress might consider a number of options to increase the innovative output of the private sector. If the Congress elected to pursue certain of these options, however, it would have to establish a new agency or modify an existing one to administer the new programs.

Options

One option the Congress could adopt would be simply to increase funding for existing programs. Alternatively, the Congress might want to develop new programs. Some of these options described below apply to industry generally, but some would affect only particular industries.

Technology Transfer. The government makes the most efficient use of its R&D expenditures if the technologies it develops for one purpose can also be used for other purposes. When someone in the private sector is the additional user, the process is commonly called technology transfer. While over 35 percent of government-supported R&D is performed in government-owned laboratories, only a limited amount of these technologies have direct commercial applications. Nevertheless, improving communication between researchers in the private sector and those in government laboratories could lead to better commercial use of government research. Such contact may help government researchers be more attuned to the commercial implications of their work and enable private researchers to appreciate more fully the research being done in government laboratories. The Congress might, therefore, consider increasing the interaction between researchers employed by government laboratories and those employed by firms.

Privatize the National Labs. A number of the national laboratories are among the nation's finest research facilities. Yet, they work almost exclusively for one client--the federal government. Private sector use is generally limited to specialized equipment, such as particle accelerators. If some of the 700 national laboratories were made into private--but perhaps nonprofit--institutions, firms in the private sector may be able to make better use of their expertise. Moreover, by working on projects for both the private sector and the government, a lab might be able to operate more efficiently. But privatizing the labs could result in significant costs. For example, efforts to gain contracts from the private sector may detract from ongoing research. In fact, private sector demand for the services that the laboratories offer may not be particularly strong. Finally, privatization runs the risk of adversely affecting the quality of the labs' ongoing efforts.

Procurement. In terms of commercial impact, procurement has been the most successful of all the federal R&D programs and has produced an array of significant civilian spillovers. The effect on the private sector, however, has never been central to government procurement. Moreover, new products being developed for the military, which does the bulk of the government procurement, seems to be spawning fewer civilian spillovers. Consequently, the Congress might consider paying increased attention to potential commercial applications in making procurement decisions. In fact, the government might support R&D to develop products for nonmilitary branches of the government. These products could range from photovoltaic cells to office equipment. Such products would be more likely than new weapons to yield commercial spillovers. On the other hand, given the government's limited experience in commercial ventures, it may have difficulty in spawning commercially successful new products.

Joint Funding. Recently, the government has jointly funded R&D projects with various consortia of firms from the private sector. Such projects have a number of advantages. Since they are supporting the research, firms presumably have an active interest in the results. In addition, because numerous firms are involved, the research frequently addresses generic issues and therefore stimulates research by the individual firms as they attempt to develop commercial applications. The advantages of such an approach will be limited, however, if the projects reduce R&D that the government or private firms would have devoted to other projects. The advantages would also be reduced if the research conducted in response to the government's efforts would have been performed in any case.

Foster New Industries. The government could target particular technologies with the hope of fostering a new industry. Government support for research has fueled the growth of a number of industries and, at the same time, thrust U.S. firms into positions of world leadership--the recent emergence of the biotechnology industry is a vivid example. Yet, the prospect of these commercial benefits was largely incidental to the funding decision. The Congress might consider making it an objective of the government to identify and support emerging technologies. In other words, the government would fund research and help disseminate results that form the bases of promising new technologies. A risk of such a strategy is that the government would not succeed in identifying emerging technologies. Forecasting future commercial and technological developments is a difficult task and one in which the government has little expertise.

Who Would Choose?

Some of these options would involve a significant expansion of the government role in the nation's R&D effort. In particular, they would require that the government monitor economic and technological developments and determine which areas are promising. At present, no agency within the government performs such a function. Consequently, if the Congress decides to expand the government's role in the innovative process--and particularly if it wants to target particular industries or technologies--then it will have to either create such an agency or expand the functions of an existing agency.

A number of agencies--including the National Science Foundation, the National Bureau of Standards, and the Department of Defense--both sponsor R&D and interact with the private sector. But none of them currently has the expertise to determine the particular industries and technologies that would benefit from government assistance. Thus, if the Congress adopts programs geared to technologies specific to certain industries, it might want to expand the mission of one of these agencies. Alternatively, the Congress might consider creating an entirely new agency, which could include functions from existing organizations.

CHAPTER I

COMPETITION, TRADE, AND INNOVATION

Some analysts believe that the huge U.S. trade deficits of the 1980s demonstrate that U.S. industry can no longer compete effectively in world markets. In this sense, the deteriorating trade balance has brought to the fore a number of concerns about U.S. industry--its productivity, the quality of its products, and its ability to turn scientific and engineering discoveries into new products. Yet, no evidence exists that the productivity and innovativeness of domestic manufacturers have suddenly and dramatically declined relative to that of their foreign competitors. Instead, differing macroeconomic policies of the United States and its principal trading partners have largely been responsible for the soaring trade deficit.

Increasing the innovativeness and productivity of domestic manufacturers would enable the United States to produce more from its limited resources. Such an increase, in turn, would limit the adverse effects that a shrinking trade deficit might have on the nation's standard of living. Indeed, a host of bills has been introduced in the Congress to improve the nation's competitiveness and, thereby, reduce the trade deficit. Because the trade deficit is largely a macroeconomic phenomenon, however, programs aimed at increasing the productivity and innovativeness of U.S. industry would not--even if they were successful--reduce the deficit by much. Moreover, even this small reduction would be realized only after a number of years.

Under many of these legislative proposals, the federal government would assume a larger role in stimulating commercial innovations. Although the government currently funds a large portion of the nation's innovative activities, it provides little direct support for purely commercial efforts. This report examines how the federal government might design programs to promote commercial innovations. While successful programs of this type would do little to narrow the trade deficit in the near term, they might nevertheless provide future benefits to the economy.

DEFINING COMPETITIVENESS

The term competitiveness is often used ambiguously. Frequently, people equate the issue of competitiveness with the balance of trade; yet, that is not what they really mean. Despite the rise in the trade deficit, the real issue of competitiveness is concerned not so much with whether trade is balanced as on what terms balanced trade will occur. In fact, concerns about competitiveness first emerged in the 1970s when U.S. trade was balanced.

What Is Competitiveness?

Put positively, competitiveness is the ability to produce and sell goods internationally while maintaining a high and increasing standard of living. Central to the notion of competitiveness, therefore, is the ability of a nation to increase steadily its real wages and incomes.1/ While a lower-valued dollar would reduce the trade deficit, it would also increase import prices and thereby lower real incomes in the United States.2/ It should be noted that, as recent U.S. experience indicates, a nation's exports and imports do not respond instantly to changes in the value of its currency.

A nation is better off if it can sell its goods when its currency is valued highly than when its currency has a low value in foreign exchange markets. Many poor countries have balanced their trade by lowering the value of their currency, making it easier for their manufacturers to sell both at home and abroad. But by doing so, they have also reduced their living standards. Other things being equal, the greater the purchasing power of a nation's currency (that is, the higher the exchange rate), the more resources that nation's currency will be able to command and the higher will be its standard of living.

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1. See, for example, Stephen S. Cohen and John Zysman, "Manufacturing Innovation and American Industrial Competitiveness," *Science* (March 7, 1988), pp. 1110-1115.

2. This proposition assumes that the economy is fully employed. If it is not, a reduction in the value of a nation's currency might stimulate exports and therefore increase domestic employment and output. The increased employment in the domestic economy could compensate for the higher import prices.

The intrinsic qualities of products being bought and sold in international markets--such as their features and durability--play an important role in determining the value of a nation's currency. They are not, however, the only factors. With flexible exchange rates and global capital markets, the macroeconomic environment in which trade takes place also plays an important role. In other words, the monetary and fiscal policies of the various national governments have critically influenced exchange rates.3/

Specifically, the federal budget deficit of the United States not only increased U.S. demand for foreign and domestic goods, but it increased real interest rates as well. These higher interest rates made U.S. securities more attractive to foreign investors who bid up the value of the dollar. Although the value of the dollar has fallen sharply since 1985, patterns of trade have yet to adjust fully. As discussed below, this series of events--and not a sudden and drastic decline in U.S. productivity and workmanship of domestic manufacturers relative to foreign manufacturers--caused the trade deficit.

Benefits of Increasing Competitiveness and the Role of Innovation

A substantial depreciation of the dollar, while balancing trade, could adversely affect the standard of living in the United States. Increased productivity and innovativeness, however, can lessen these adverse effects. If domestic manufacturers became more productive, for example, the United States would need fewer of its own resources to meet foreign demand. With fewer resources needed to make the products to be exported, more resources would be available to make goods and services for domestic consumption.

Introducing new products, another aspect of innovativeness, can also increase a nation's welfare. Often a firm introducing a product can generally price the product--at least for a while--above the value of the resources used to produce it. Increasing foreign sales of new products means that fewer domestic resources would be used for each

3. See, for example, Congressional Budget Office, *The Economic and Budget Outlook: Fiscal Years 1989-1993* (February 1988), pp.3-14.

dollar of exports. Consequently, as in the case of higher productivity, more resources would be available to make goods and services for domestic consumption.

Thus, innovativeness is integrally linked to U.S. competitiveness through new products and new production processes. Increasing the nation's output of innovations can have important benefits regardless of the balance of trade; for example, it enables a society to use its resources more productively. The federal government already plays a major role in funding research and development and therefore plays an important role in the nation's innovative efforts. Federal financing of research and development has had enormous commercial spillovers in a number of industries including semiconductors and computers. Yet, with a few minor exceptions, the government does little to encourage commercial innovation explicitly.

A primary purpose of this report is to consider ways in which the government could stimulate commercial innovations. As has already been noted, however, even if these programs successfully stimulated innovative activities, they would not affect the trade deficit for a number of years. Generating new ideas and incorporating them into new products or processes is a time-consuming process. Moreover, it will also take time for the government to establish such a program and for that program to affect industrial efforts. As a result, any decision to encourage further civilian innovation should be based on its long-run effect on the nation's standard of living rather than on its impact on the trade deficit.

THE COMPETITIVENESS OF U.S. INDUSTRY

From the end of World War II until 1972, the United States consistently recorded trade surpluses in manufactured goods. Even during the 1970s, U.S. imports of manufactured products roughly matched exports. Nevertheless, analysts increasingly believed that the competitiveness of domestic industry was declining. A growing number of industries experienced greater foreign competition and, more importantly, increased imports. In addition, exports of domestic factories accounted for a shrinking share of total world exports.4/ This increased competition stemmed from, among other things, the rebuilding of war-ravaged industries in Japan and Europe, improved international transportation and communication, and a reduction in tariffs. Nonetheless, other measures provide different views of how well domestic firms are able to compete internationally.

Evidence of Declining Competitiveness

Central to the notion of competitiveness is how productively domestic producers use a nation's limited resources. Also critical to a nation's competitiveness is the relative ability of domestic manufacturers to introduce new products and adopt new production processes. Yet, there are problems in measuring both.

Because of these measurement problems, evidence of a decline in the ability of U.S. manufacturers to compete against foreign firms is largely anecdotal. In fact, many of the stories relate to the steel and automobile industries.5/ These were among the largest and most profitable domestic industries through much of the twentieth century. Imports adversely affected both of them. Major steel producers in the United States lagged behind their foreign competitors in adopting significant innovations, such as the basic oxygen furnace and continuous casting, while wage rates in the industry rose faster than the average of all manufacturers. Moreover, automakers in both Japan and Europe established reputations for being more efficient than domestic manufacturers and also for producing higher-quality cars.

Foreign competition has also increased in the markets for new products. This change became most evident in the 1980s. A domestic firm developed the technology underlying the most rapidly growing consumer electronic product of the decade--the videocassette recorder--yet it is not produced in the United States. Although the U.S. semiconductor industry initially dominated the rapidly growing

4. See, for example, Robert Lipsey and Irving Kravis, "The Competitiveness and Comparative Advantage of U.S. Multinationals, 1952-1983," National Bureau of Economic Research, Working Paper, October 1986.

5. For a discussion of these and other industries, see Lester Thurow, "A Weakness in Process Technology," *Science* (December 18, 1987), pp.1659-1663.

market for dynamic random access memory chips, Japanese firms quickly grabbed the lead in world markets. Furthermore, foreign firms are among the pioneers in a number of emerging fields such as advanced ceramics and robotics. Finally, residents of foreign countries were awarded 47 percent of patents issued by the United States in fiscal year 1987. This figure was up from 38 percent in 1980 and 26 percent in 1970.6/

Evidence of Continuing Competitiveness

Offsetting these indications of flagging competitiveness are alternative measures demonstrating that competitiveness may not have deteriorated by much, if at all, despite the mushrooming trade deficit.

Productivity. The one index that comes closest to measuring competitiveness--labor productivity--suggests that U.S. manufacturing actually improved during the 1980s. Since 1960, the growth in labor productivity in the United States lagged behind that of its principal trading partners (see Table 1).7/ During the 1970s, the gap was especially large. But the productivity growth rate of domestic manufacturers accelerated during the 1980s. Consequently, U.S. productivity grew faster than it had in previous decades, most notably after the 1982 recession. In fact, the growth rate in the productivity of U.S. manufacturers is approaching that of Japan and West Germany. More significantly, manufacturing output per labor hour, as opposed to its rate of growth, generally remains higher for firms in the United States than for the firms of its principal trading partners.

Nevertheless, these statistics should be interpreted with caution; there can be problems comparing output per man-hour among countries. For example, the measure ignores the fact that, because the relative prices of inputs differ among countries, firms do not neces-

6. In addition to innovative output, this statistic also reflects changes in the inclination of manufacturers in various countries to patent their inventions in the United States.

7. A number of recent publications discuss this development in greater detail. See Molly McUsic, "U.S. Manufacturing: Any Cause for Alarm?" *New England Economic Review* (January/February 1987), pp. 3-17; Council of Economic Advisers, *Economic Report of the President* (January 1987), p.46; Congressional Budget Office, *The Economic and Budget Outlook: Fiscal Years 1988-1992* (January 1987), pp. 79-95.

TABLE 1. MANUFACTURING PRODUCTIVITY IN SELECTED COUNTRIES

	United States	Canada	Japan	France	Germany	United Kingdom
	Growth in Output per Hour (Percentage, annual rate)					
1960-1985	2.7	3.4	8.0	5.5	4.9	3.6
1960-1973	3.2	4.7	10.5	6.5	5.9	4.3
1973-1980	1.2	1.6	7.0	4.6	3.8	1.0
1980-1985	3.7	2.5	5.4	4.6	4.0	5.1
1982-1985	4.8	4.5	5.8	4.3	5.4	4.8
	Relative Levels of Output per Hour					
1985	100.0	86.1	95.4	82.1	93.0	59.3

SOURCE: Statistics on output per hour were calculated by the Congressional Budget Office using data from the Bureau of Labor Statistics, Department of Labor. Statistics on productivity levels are from Molly McUsic, "U.S. Manufacturing: Any Cause for Alarm?" *New England Economic Review* (January/February 1987), p. 10.

sarily use the same production processes.8/ In addition, the quality of products made by different manufacturers varies, so that comparing productivity can be misleading. Furthermore, it is virtually impossible to quantify the propensity of a nation to introduce commercially successful innovations.

Output. Imports supplement as well as substitute for domestic production; consequently, an increase in imports generally leads to increased consumption. Nevertheless, the rapid increase in imports during the 1980s undoubtedly substituted for some domestic production--that is, domestic manufacturers would have produced more had less been imported. In fact, the perception that an increase in

8. Measuring total factor productivity controls for differences in factor intensities. Making international comparisons of total factor productivity is a complex procedure, the results of which are not likely to be reliable because of a lack of comparable data. See Molly McUsic, "U.S. Manufacturing: Any Cause for Alarm?" pp. 10-12.

imports reduces domestic output and employment is a principal reason for the concern about the trade deficit.

If increased imports reduced the amount that domestic manufacturers produced, then manufacturers' share of gross national product (GNP) would fall during periods of rising imports. But manufacturing's share of GNP has remained remarkably constant through the 1980s (see Figure 1). In fact, the growth rate of manufacturing output since the end of the last recession has been greater than the average of the previous recoveries. While the share of the domestic work force employed in manufacturing has fallen, this decline simply reflects the more rapid rise of labor productivity in manufacturing industries than in other sectors of the economy. Total employment in manufacturing was essentially the same in 1986 as it was in 1965; manufacturing employment, however, was 10 percent below its post-World War II peak in 1979.

Export Shares. A recent study found that between 1966 and 1983, world export shares of U.S.-owned multinationals have remained relatively constant regardless of where the products were produced.9/ Yet, during this period, the U.S. share of world exports coming from domestic plants declined. In other words, U.S. multinationals are increasingly competing in world markets with goods manufactured outside the United States. They have apparently shifted production away from the United States to countries where they can manufacture and market particular products at lower cost.

Viewed in this way, the decline in the U.S. share of world exports does not appear to stem from a deterioration in the quality of either management or technology; U.S. firms own and operate these facilities. Rather, it reflects the realization by domestic manufacturers that they could lower costs by shifting output to other nations.

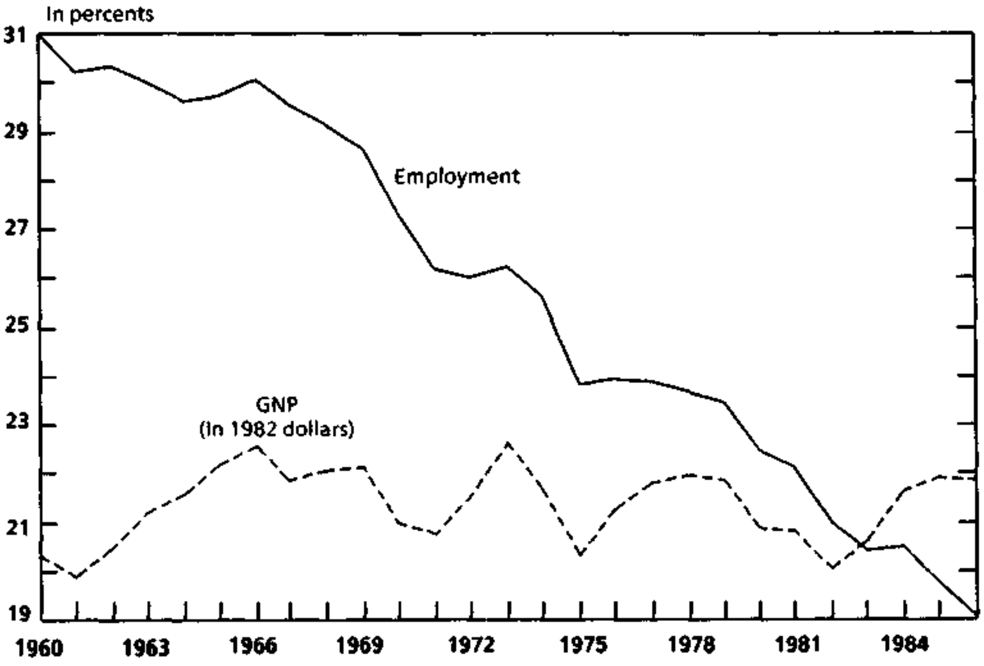
9. Lipsey and Kravis, "The Competitiveness and Comparative Advantage of U.S. Multinationals, 1952-1983." A similar finding was reported by Fred Bergsten and William Cline in *The United States-Japan Economic Problem* (Washington, D.C.: Institute for International Economics, 1985), p.108. Bergsten and Cline show that the United States-Japanese bilateral trade deficit in 1984 would have been about half as large had sales of foreign affiliates based in each country been taken into account.

In summary, little evidence supports the notion that the trade deficit resulted from a sudden decrease in the relative efficiency of domestic manufacturers. Nevertheless, increasing productivity and innovativeness in the economy is still a crucial issue since it is an essential means of improving the nation's standard of living.

INNOVATION IN THE ECONOMY

Innovation is the process of creating new products (like the polio vaccine and the transistor) or new processes (like continuous casting in the steel industry). Firms produce innovations by engaging in

Figure 1.
Manufacturing in the Economy
(Share of employment and gross national product)



SOURCE: Congressional Budget Office using data collected by the Department of Labor and the Department of Commerce.

research and development. Since it has proved virtually impossible to measure objectively a concept as qualitative as innovativeness, analysts frequently gauge innovativeness by the amount that is spent on R&D. Although this essentially entails measuring output by the cost of the inputs needed to produce it, R&D expenditures are probably the most reliable, readily available measure of innovativeness, although the relationship is certainly not an exact one.10/

Firms invest in R&D to innovate, and they innovate to earn profits. When a firm introduces a new product, it can--at least for some period--price the product above its manufacturing costs. Similarly, a process innovation generally lowers the cost of the product more than it lowers the product's price. An innovation--whether it is a product or a process--will be profitable if the future profits from it, appropriately discounted, exceed the costs of innovating.

From society's perspective, firms may not perform enough R&D and may emphasize the wrong kinds of projects. It is not uncommon for markets to provide signals to firms regarding R&D that do not accurately reflect society's needs; a firm makes decisions based on its benefits and costs that are not necessarily the same as the benefits and costs to society. For example, firms tend to engage in less R&D than is socially desirable, especially in areas that appear to hold little likelihood of yielding near-term commercial applications. It is this type of research where the costs and benefits of the firm are most likely to diverge from those of society. At the same time, firms tend to devote too large a share of their efforts to research that duplicates the efforts of others or otherwise does not increase society's stock of knowledge.

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10. The R&D expenditures needed to produce an innovation can differ substantially among industries and even among firms in the same industry. In the first place, the technological opportunities surrounding some industries are much greater than others, so a given level of R&D produces more innovations. In addition, some firms are more efficient at innovating than others. Finally, a given amount of R&D can produce more innovation in one firm than another simply by a matter of chance.

Classifying R&D Activities

In discussing the innovative process, it is helpful to divide research and development into three categories--basic research, applied research, and development.11/

- *Basic research* consists of investigations whose primary purpose is to advance knowledge without regard to specific commercial applications. This category includes research on the behavior of subatomic particles or unraveling the genetic code.

- *Applied research* consists of investigations aimed at advancing scientific knowledge with the ultimate aim of producing a new product or process. This category includes such efforts as exploring the properties of steel with the hope of developing a less corrosive product or studying radio waves to improve television reception.

- *Development* is the process by which new knowledge is incorporated into new products and processes, including the design and production of prototypes.

The stages of research and development are often viewed as a pipeline. In this view, innovations emerge from a straightforward and orderly process that begins with a basic scientific discovery and concludes with a commercial product. In practice, the innovative process is often more haphazard than the pipeline analogy suggests; in fact, the various stages of R&D are often pursued simultaneously.12/

The events following the recent discovery of a new class of materials that achieve superconductivity at relatively high temperatures

11. See National Science Foundation, *Research and Development in Industry* (Washington, D.C.: NSF, 1984), pp. 2 and 3.

12. See, for example, Congressional Budget Office, *Federal Support for R&D and Innovation* (April 1984), pp. 8-10.

illustrate this point.13/ After the initial discoveries, scientists simultaneously began to investigate why the new materials were superconductors (basic research), to find materials that could carry increased quantities of electric current (applied research), and to create wires from the new materials (development). Moreover, the results in one stage of research often benefit efforts in other stages. Bell Laboratories, which actively pursues all three categories of R&D, has established a reputation as a place where applications drive basic science.

Even in cases where the pipeline analogy holds, a substantial amount of time can elapse between the basic research discovery and the ultimate introduction of a product. In some cases, this lag results from the significant amount of applied research as well as development that is required to turn a basic research finding into a new product. It is also the case, however, that the commercial implications of a discovery are only fully appreciated at a much later date. For example, Dupont invented teflon in the 1930s, but it was not until the space program of the 1960s that practical applications for the material were uncovered.

While the notion of an innovation spawns thoughts of revolutionary new products, most innovations involve relatively small modifications of existing products or production methods. Nevertheless, viewed over an extended period of time, these incremental improvements often add up to substantial changes in an industry's products and processes. The automobile of the 1980s is vastly different from its predecessors of the 1950s; yet, no single major innovation accounts for the difference.

The Uncertain Payoffs of Research and Development

R&D differs in a number of ways from other types of investments that firms make. In the first place, others can gain from a firm's research

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13. Superconductivity has not yet yielded any commercial products and thus is not truly an innovation. For a discussion of the discovery and the future implication of these new materials, see "A Current of Change for Motors and Computers," *The Washington Post*, May 18, 1987, p.A-1. For a more general view of this process, see Stephen Kline and Nathan Rosenberg, "An Overview of Innovation," in Ralph Landau and Nathan Rosenberg, eds., *The Positive Sum Strategy* (Washington, D.C.: National Academy Press, 1986), pp. 235-294.

without compensating it. In addition, R&D is riskier than most other investments. Consequently, left to their own devices, firms tend to invest less in innovative activities than would be socially desirable.

Appropriability. The speed at which competitors can replicate--or appropriate--an innovation critically affects the profits of the innovating firm. The more rapidly other firms can copy the new product or process, the sooner they can introduce competitive products or lower their production costs. In the extreme, where other firms immediately copy the new product or process, an innovating firm would not earn any profits from its innovation. Clearly, without the prospect of profits, firms have no reason to invest in research and development.

While no innovation can be copied immediately, most can be duplicated within a relatively short period of time. Moreover, it costs less to copy an innovation than to introduce it. One study found that developing an imitation costs only 65 percent of the cost of the original innovation.14/ As discussed elsewhere in this report, patents provide only limited protection, especially for process innovations. In contrast, when a firm purchases a piece of equipment, it maintains complete control of its use. A firm investing in R&D, however, cannot fully appropriate the fruits of its efforts.

This lack of appropriability discourages firms from performing R&D, but it also affects the mix of R&D projects that firms do conduct. For example, the difficulty in keeping research results proprietary is greatest with basic research. Scientists doing basic science generally find it useful to keep abreast with ongoing research in their field. Consequently, they disseminate their findings widely by publishing in professional journals and making presentations at professional meetings.15/ By the same token, firms tend to emphasize research and development that yield outcomes with the fewest problems of

14. This figure is an average; the relative cost of imitating varies considerably among industries. See Edwin Mansfield, "Microeconomics of Technological Innovation," in Ralph Landau and Nathan Rosenberg, eds., *The Positive Sum Strategy*, p.313.

15. Research in general, and most notably basic research, shares some of the characteristics of a public good. Consumption of a public good by a person or group of people does not reduce the amount available for others to consume. National defense is the clearest example of a public good. The use of a research result by one firm may, however, reduce the value of using that research result by another firm.

appropriability. Moreover, applied research and development are more likely than basic research to produce patentable inventions.

Although patents provide some limit on the ability of others to copy an invention, they do not remove the problem of appropriability. While a patent grants an inventor exclusive rights to his or her invention, the results of the invention can often be achieved in other ways. For example, the VHS and Beta formats are different systems that can be used to achieve the same result: recording video images. Thus, while patents encourage innovative activities, they also encourage firms to engage in research efforts that largely duplicate the efforts of the innovator. As a result, substantial resources may be expended in performing research that does not substantively increase the nation's stock of knowledge.

Risk. Research and development tends to involve greater risks than other investments; for potential investments that have the same expected profits, the range of possible profits and losses from an investment in R&D tends to be wider. Since firms prefer investments that are less risky, R&D projects tend to be less attractive than other projects, although firms earn higher rates of return on R&D than they do on other investments.16/

Yet, the risks to society from R&D projects are much less than the risks to a given firm. If many risky projects are performed at once, some will be successful while others will not, and the range of possible profits and losses is reduced. A firm is obviously less able than society to pool the risks of many research projects.

Research and development is riskier than most other investments for a number of reasons. Fundamentally, it is often difficult to predict the costs of producing a particular innovation, let alone how profitable the innovation might ultimately prove to be. In addition, long delays often occur between the time when research begins and when a new product or process is introduced.

Further, unlike an investment in plant and equipment, an investment in research and development does not produce a tangible

16. For a summary of estimates on the returns to research and development, see Congressional Budget Office, *Federal Support for R&D and Innovation* (April 1984), pp. 28-31.

product. If sales are lower than a firm expected when it made an investment in plant and equipment, the firm usually can, at least for a while, earn revenues in excess of the variable costs of operation and then ultimately sell the plant and equipment to recover some of the purchase price. In contrast, if an R&D project does not produce commercial applications, a firm cannot similarly mitigate its losses.

The risks are greatest for those projects that strive for significant technological advances. Such projects not only require substantial expenditures, but the distinct possibility always exists that these efforts will fail to produce any commercial applications whatsoever. The greater risk associated with basic research and the search for major technological breakthroughs is another reason that firms tend to concentrate their R&D efforts on development.

Public and Private Roles in R&D

Because of the problems of risk and appropriability, firms do not devote enough resources to research and development--at least, from society's perspective. In addition, firms place too much emphasis on those R&D projects that promise to yield immediate commercial applications and not enough on those that might yield significant technological advances. In other words, from society's perspective, market signals tend to lead firms to both underinvest in R&D and invest in the wrong mix of R&D activities.

As has been previously noted, the inability of inventors to capture the full value of their inventions, as well as the riskiness of R&D, largely explains the shortcomings in the private sector's R&D efforts. This is most true of efforts geared toward creating major innovations that have far-reaching societal impacts. In addition, firms have little incentive to undertake certain kinds of research--the effects of diet on health, for example.

The federal government has consistently funded a large share of the nation's R&D efforts. While it directs much of this effort in pursuit of its own missions--developing weapons systems, for example--a great many of its efforts are directed in those areas where the private sector tends to underinvest. The government's efforts in this regard directly follow the pattern of the innovative process as a pipeline in which innovations flow directly from basic through applied research. Because the private sector has little incentive to expend resources on basic research, the government helps to fill this void. It does so, at least partly, with the expectation that private firms will be able to use the results of this research in their own applied research and development. As subsequent discussions will indicate, however, this view of the innovative process may be an overly simplified one.

CHAPTER II

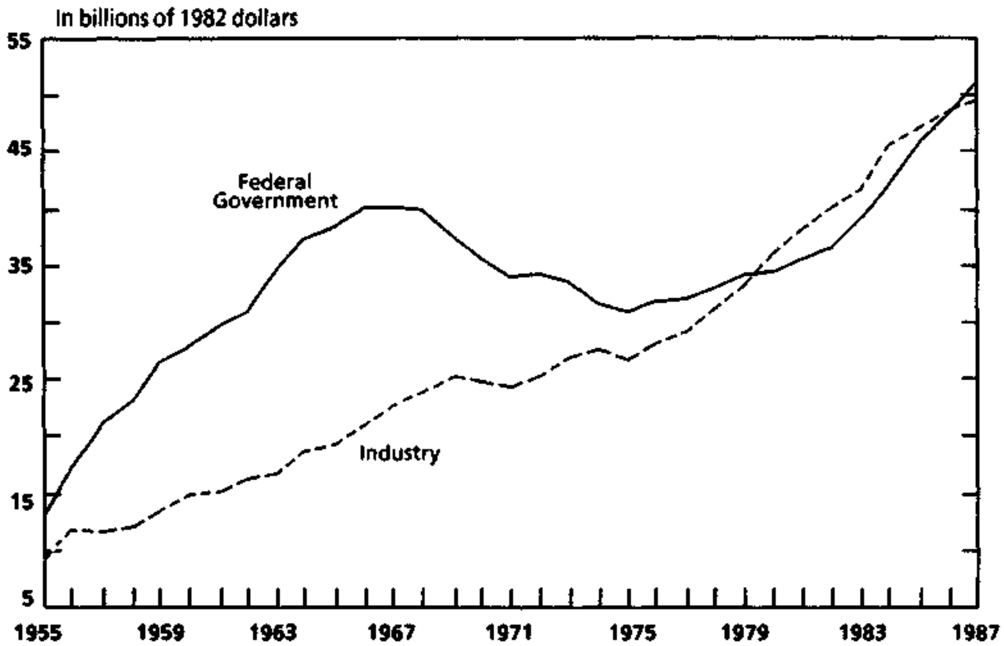
TRENDS IN U.S. R&D EXPENDITURES

Firms in developed nations generally compete most successfully in the production and sale of technologically sophisticated products. Because of their relatively high labor costs, manufacturers in advanced economies must continually introduce new products and increase their efficiency to compete effectively. Thus, given the growth in international competition, one would expect the United States to devote an ever-increasing share of its resources to research and development. Yet, the ratio of U.S. R&D expenditures to gross national product was lower in 1986 than it was in 1966. A decline in federal support for R&D in the 1970s was largely responsible for this decline in the intensity of R&D. Moreover, private funding during the 1970s did little more than keep pace with the growth of the economy.

AN OVERVIEW

For the past 20 years, the government and industry have consistently financed over 95 percent of the nation's research and development efforts. While the government has spent more than industry on R&D through most of the post-World War II period, it has been the less dependable supporter (see Figure 2). Moreover, the federal government does not have an explicit R&D budget. Support by the various government agencies for research and development has ebbed and flowed as societal concerns have changed. Because of reduced government support for R&D during the 1970s, the United States lost its position as the most R&D-intensive of the world's democratic nations. And despite the rapid increase in R&D spending for defense during the 1980s, the R&D intensity of the U.S. economy nevertheless lags behind that of Japan. Such comparisons are even less favorable to the United States when military expenditures are excluded.

Figure 2.
U.S. Research and Development Expenditures



SOURCE: Congressional Budget Office using data supplied by the National Science Foundation.

The Three Epochs

One analyst detects three discrete periods in U.S. post-World War II research and development efforts, with the government's role changing accordingly.1/ From the end of World War II through the mid-1960s, the "Cold War" and the Soviet Union's launching of Sputnik exerted an important influence on U.S. R&D efforts. Defense- and space-related efforts dominated not only the government's but also the nation's research agenda. By the mid-1960s, government funding of these activities accounted for 55 percent of the nation's R&D efforts, both public and private.2/

1. See Harvey Brooks, "National Science Policy and Technological Innovation," in Ralph Landau and Nathan Rosenberg, eds., *The Positive Sum Strategy* (Washington, D.C.: National Academy Press, 1986), pp. 128-135.

2. National Science Foundation, *National Patterns of Science and Technology Resources, 1986* (Washington, D.C.: NSF, March 1986), p. 41.

In the second half of the 1960s, at the start of what might be called the second epoch, the nation's agenda shifted toward the use of science (including the social sciences) to address such societal problems as air pollution, poverty, and eventually skyrocketing oil prices. Despite the increased support for civilian R&D, real government expenditures actually declined by 20 percent between 1967 and 1975. Although private sector R&D expenditures increased by 18 percent during this period, they still lagged behind the growth of GNP. Private sector R&D expenditures, however, grew slightly faster than the increase in the output of domestic manufacturers. But greater government regulation of the environment as well as higher oil prices forced industry to devote an increasing share of its resources to developing cleaner and more fuel-efficient production processes and products.3/ These activities did little to enhance, and may have actually limited, the growth in productivity of domestic manufacturers.4/

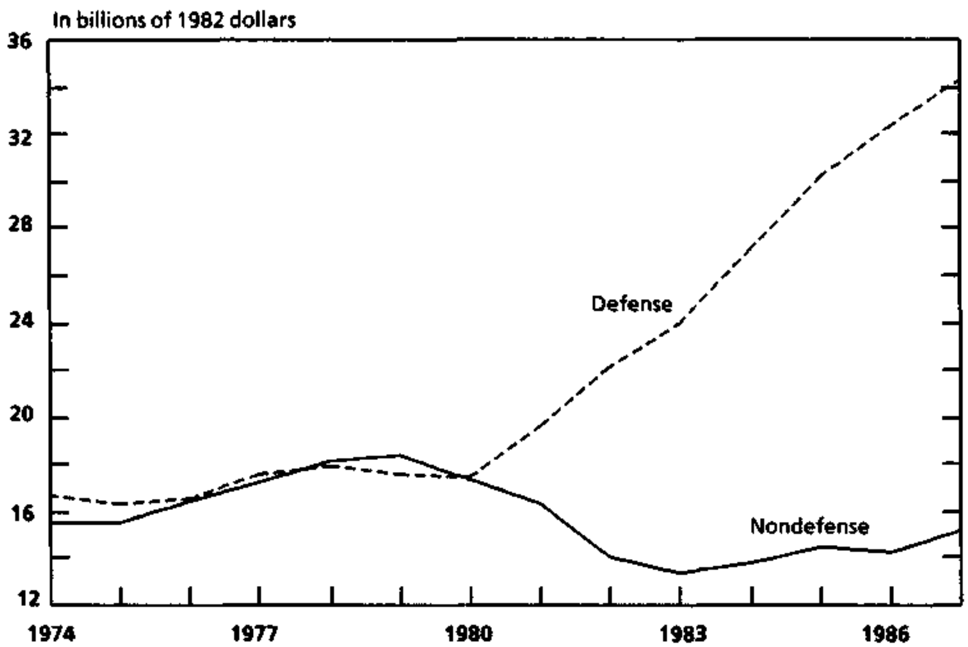
In the latter part of the 1970s, or during the third epoch, the nation increasingly viewed science and technology as the way to become more competitive. Real R&D expenditures by domestic manufacturers increased by more than 6 percent a year between 1975 and 1981. Expenditures by private industry continued to grow at that rate through 1984. And in contrast to previous patterns, real private R&D expenditures grew during the back-to-back recessions of the early 1980s. Nevertheless, since 1984, the growth rate in private sector spending has been slipping; it grew at an average annual rate of less than 3 percent between 1984 and 1987.

During the second half of the 1970s, real government expenditures reversed an eight-year contraction and resumed their growth. Nevertheless, it was not until the 1980s that real government funding of R&D grew more rapidly than real GNP and approached the growth rate of industry expenditures. Unlike industry, government expenditures have continued to grow at an average annual rate of 6 percent

3. The share of company-funded R&D used for pollution abatement or energy conservation increased from 9 percent in 1973 to 13 percent in 1979. The National Science Foundation does not publish this data for years before 1973, when the percentage was presumably much smaller.

4. In fact, some evidence indicates that R&D expenditures or pollution abatement are negatively related to growth in productivity. See, for example, Albert Link, "Productivity Growth, Environmental Regulators and the Composition of R&D," *Bell Journal of Economics* (Autumn 1982), pp.548-557.

Figure 3.
Federal Research and Development Expenditures:
Defense versus Nondefense



SOURCE: Congressional Budget Office using data supplied by the National Science Foundation.

since 1984. But the government has directed its increased support largely to the military; expenditures on civilian projects were lower in 1987 than they were in 1980 (see Figure 3 above). Yet, a number of civilian programs--health research, for example--did receive increased government support.

During the 1980s, the Congress provided indirect support for commercial innovativeness by modifying patent, tax, and antitrust laws.5/ In addition, several agencies established programs--such as the Engineering Research Centers by the National Science Foundation and Mantech by the Department of Defense--that help develop new manufacturing technologies. But such efforts involved less than one-half of

5. These legislative actions are discussed more fully in the next chapter.

1 percent of the more than $50 billion the government spent on research and development in fiscal year 1986.

International Trends

Between 1970 and 1986, real R&D expenditures grew less rapidly in the United States than in other industrialized nations. While U.S. expenditures averaged only a 3 percent growth rate, expenditures in Japan grew at an average annual rate of 7.4 percent, and in Germany they grew by 4.1 percent. These growth rates, however, were not uniform throughout the period. Germany's R&D expenditures grew at a slower rate during the 1980s than they did in the 1970s. In the United States, R&D increased at a faster pace during the 1980s.

R&D represented 2.9 percent of the U.S. gross national product in 1964 (see Figure 4). But this share fell more or less continuously until the late 1970s; it reached 2.1 percent in 1977. None of the other major industrialized countries experienced similar declines. In fact, the R&D intensity of West Germany has doubled since the 1960s, and Japan's R&D intensity increased almost as rapidly. In the late 1970s, West Germany became the most R&D-intensive economy of the major free market economies, although Japan surpassed both the United States and West Germany in the 1980s. Nevertheless, in absolute terms the United States spent two and one-half times as much on R&D as Japan did in 1985, and five times as much as West Germany.6/

R&D intensity is supposed to provide some indication of the technological progressiveness of an economy. But the large commitment to defense is an important reason why the U.S. economy has about the same R&D intensity as Japan and West Germany. If R&D for defense provides only limited benefit to the manufacturing of civilian products, measuring R&D intensity without military expenditures may provide a more meaningful comparison. When this measure is used, both Japan and Germany are significantly more R&D intensive than the United States. In fact, since 1971, civilian R&D as a percentage of GNP has increased by more in West Germany and Japan than in the

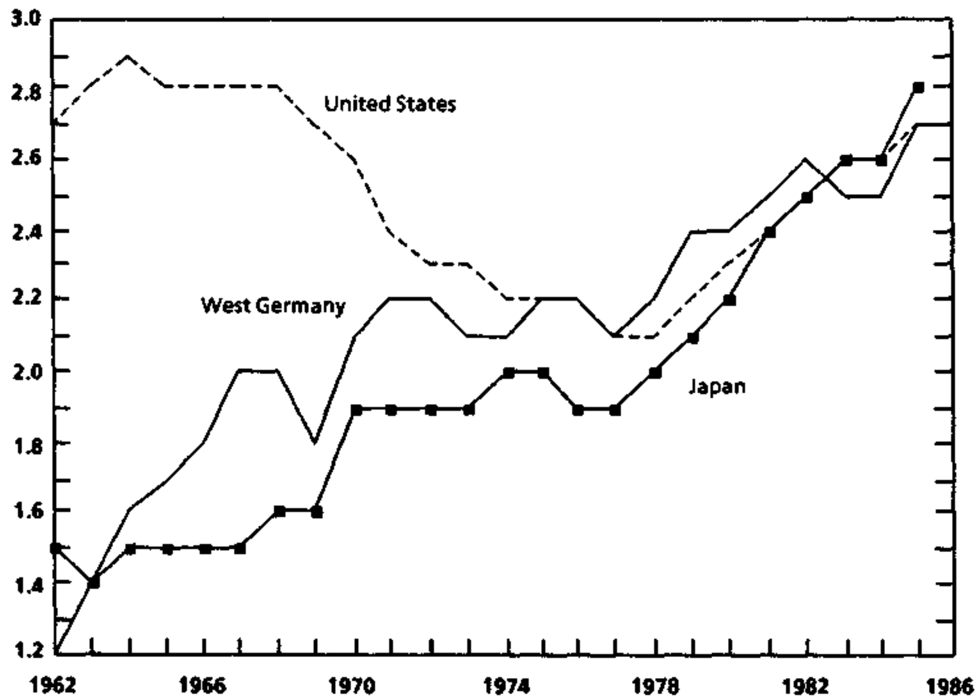
6. *International Science and Technology Update 1987* (Washington, D.C.: National Science Foundation, December 1987), p. 3.

United States (see Figure 5). Defense has consistently accounted for more than half of the U.S. government's commitment to R&D. The defense share of government-funded R&D in West Germany has never exceeded 15 percent, and in Japan it has rarely exceeded 2 percent.

GOVERNMENT SUPPORT OF R&D

Government support of R&D has been critical to a number of the nation's innovative efforts; among the more notable examples are the

Figure 4.
Research and Development Expenditures in Selected Countries
(As a percent of gross national product)

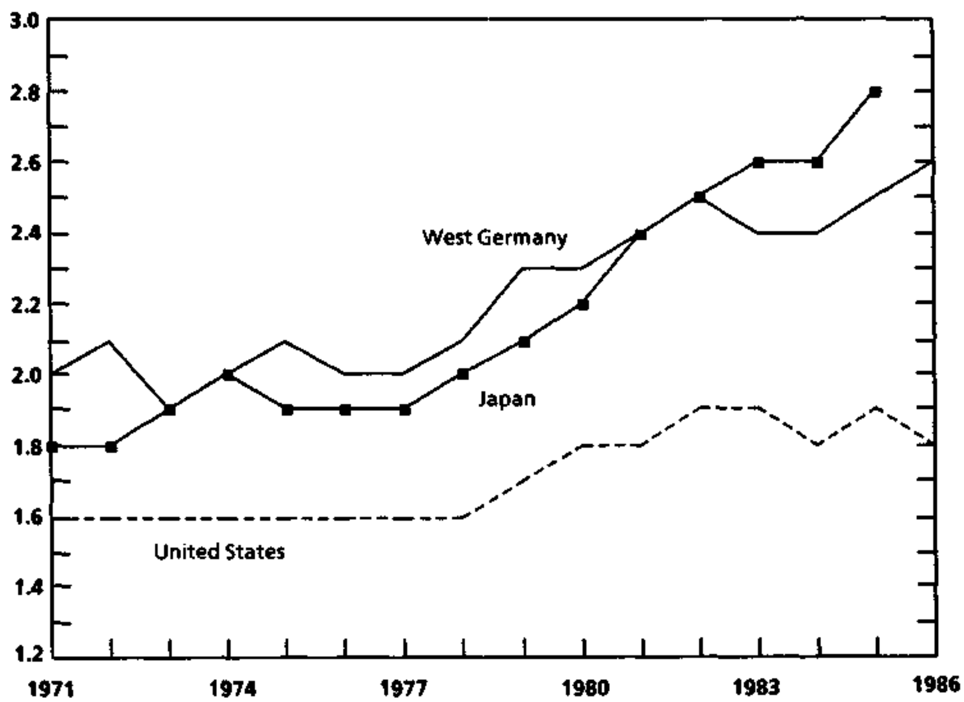


SOURCE: Congressional Budget Office using data supplied by the National Science Foundation.

NOTE: Data for 1984 are preliminary; data for 1985 and 1986 are estimates.

development of jet aircraft, semiconductors, and computers. Yet, little of the government's R&D expenditures are made with the explicit purpose of aiding domestic manufacturers. Even when government R&D did produce commercial innovations, there was often a long gestation period. Thus, it is unclear to what extent the larger government spending of the 1980s has increased the competitiveness of domestic industry.

Figure 5.
Nondefense Research and Development Expenditures in Selected Countries (As a percent of gross national product)



SOURCE: Congressional Budget Office using data supplied by the National Science Foundation.

NOTE: Data for 1984 are preliminary; data for 1985 and 1986 are estimates.

Does Government R&D Affect Competitiveness?

Analysts have measured the impact of federal R&D on the private sector in a number of ways. For the most part, their efforts have focused on research and development that private firms perform under contract to the government. These activities account for nearly half of government R&D and, for the most part, are financed by the military. Presumably such contract R&D provides larger and more direct benefits to firms--most notably to those performing the research--than other types of support.

To gauge the impact of direct government support of R&D, studies have estimated the impact of these expenditures on two aspects of firms' performance--growth in productivity and private funding of R&D.7/ For the most part, these studies have found that increased government R&D does not raise productivity. A positive association does, however, exist between private R&D spending and growth in productivity. Since the bulk of military funds support the development of new products, such as weapons, it stands to reason that government R&D expenditures would not have much impact on productivity in the private sector.8/

The impact of government R&D on product innovations cannot be measured as directly. Some evidence indicates, however, that government R&D does increase this aspect of competitiveness. Contract research seldom yields products that can be both sold to the military and marketed commercially. Rather, if a contract generates a technology with potential civilian applications, a firm generally undertakes additional R&D in order to develop commercial products. A number of studies have found that government funding of private sector R&D has stimulated private sector activity. There is also evidence that government R&D benefits firms in other industries. Some studies estimate that an increase of government R&D of one dollar

7. For a review of the relevant literature, see Nestor Terleckyi, "Measuring Economic Effects of Federal R&D's Expenditures: Recent History with Special Emphasis on Federal R&D Performed in Industry," a paper commissioned for a workshop--"The Federal Role in Research and Development"--sponsored by the National Academy of Sciences, November 1985.

8. The military has tried to reduce manufacturing costs of its supplies through the Mantech program. The technologies developed through the program apparently do not have wide applications for civilian products. In any case, Mantech accounts for less than one-half of 1 percent of the Department of Defense's R&D.

will lead to as much as 50 cents of additional private sector spending. Other studies, however, have found the effect to be less than one-half as large.

There is little question that government R&D has played an important role in the development of a number of commercial products. Thus, the conclusion that government R&D stimulates private sector efforts seems incontrovertible. Yet, at least one study found the effects of government R&D on private sector spending to be negligible.9/ The explanation of this apparent anomaly, however, is straightforward. The stock of scientific equipment, and to a lesser extent the stock of scientists and engineers, cannot be instantly expanded. Consequently, increased government spending in one area may result in a diminution of effort in other areas. In this view, therefore, the increased government expenditures for defense in the 1980s detracted from civilian efforts.

Spending During the 1980s

The government directed its increased R&D efforts during the 1980s almost entirely toward defense--defense-related R&D virtually doubled between 1980 and 1987. The sharp increase in defense R&D stemmed from the military buildup and the accompanying rapid pace of weapons acquisition. Meanwhile, nondefense expenditures contracted by 12 percent. Most nondefense government agencies either reduced or increased only modestly their R&D activities.10/ As a result, the distribution of government R&D funds has changed considerably. For example, the share of government R&D for defense programs went from 50 percent in 1980 to an estimated 69 percent in 1987 (see Figure 6).

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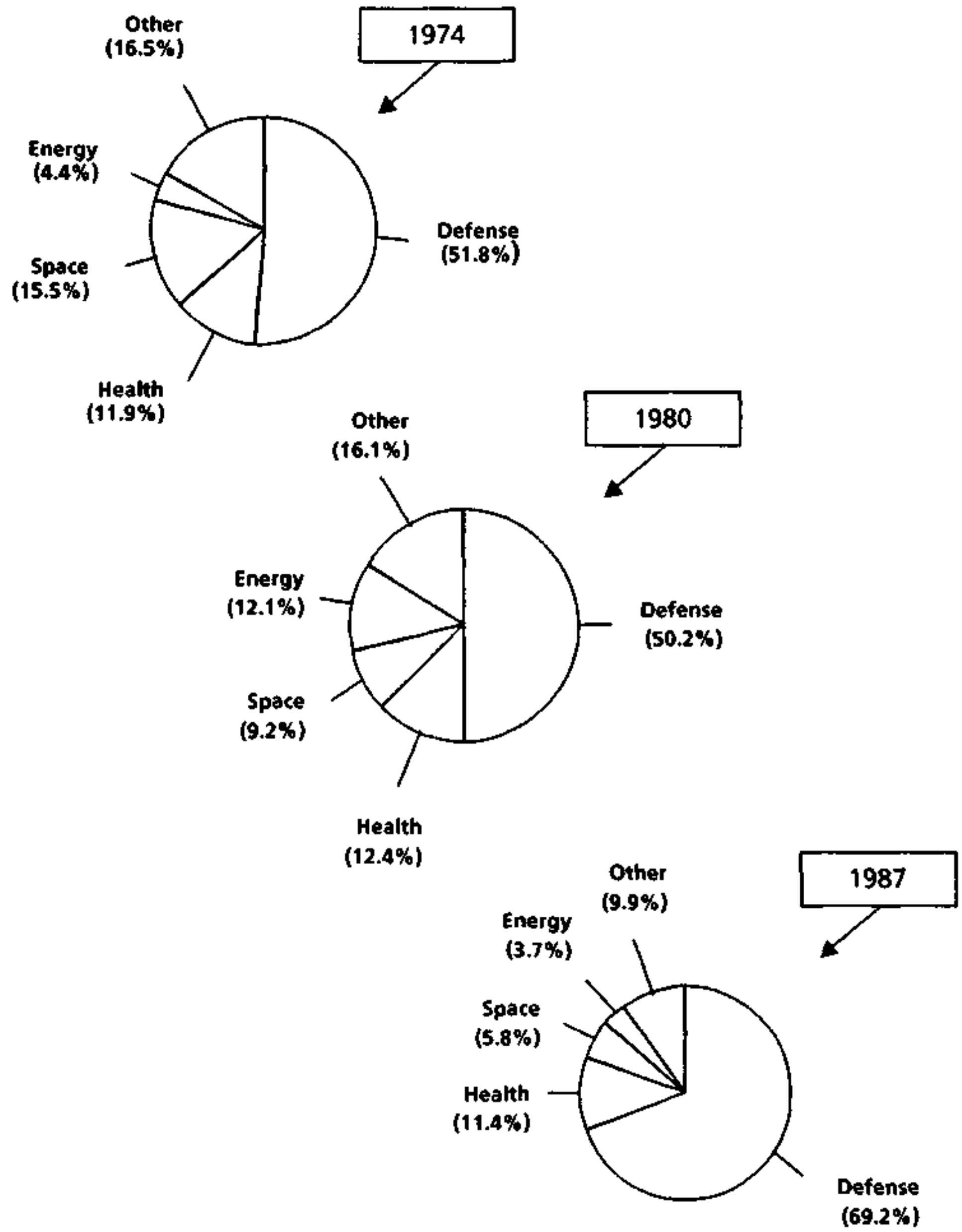
9. See F.R. Lichtenberg, "The Relationship Between Federal Contract R&D and Company R&D," *American Economic Review* (May 1984), pp. 73-78. Moreover, the government contracting process may encourage private sector expenditures and thus create a spurious correlation between private and government expenditures; see F.R. Lichtenberg, "The Potential Impact of the Strategic Defense Initiative and U.S. Industrial Competitiveness," Columbia University Graduate School of Business, unpublished paper (November 1987), pp. 6-10.

10. These data are by function. For example, military R&D includes funding by the Department of Energy as well as the Department of Defense. See National Science Foundation, *National Patterns of Science and Technology Resources, 1986.*

Figure 6.
Distribution of Federal R&D Funds for Selected Fiscal Years



SOURCE: Congressional Budget Office using data supplied by the National Science Foundation.

NOTE: Data for 1987 are estimates.

These changes are consistent with the Reagan Administration's objective of placing maximum reliance on the market in shaping the nation's research and development agenda. The government stresses those areas in which private firms have the least incentive to perform. In addition to defense, the Congress has devoted increased resources to basic research as well as R&D in health. Nevertheless, other than defense, the area most affected by these changes was R&D in civilian energy programs.

Civilian Energy R&D. The Department of Energy's (DOE's) R&D is largely conducted in national laboratories that are owned by the government but operated by universities and private firms. The largest of these labs, the so-called multiprogram labs, account for nearly 90 percent of DOE's research and development efforts. These laboratories--which include Argonne, Berkeley, Livermore, Brookhaven, and Oak Ridge--trace their origins to the Manhattan Project and the development of the atomic bomb during World War II. After the war, the Congress created the Atomic Energy Commission, in part to oversee research at the laboratories. While most of their efforts continued to involve defense applications for nuclear and atomic power, the labs also took an active role in developing commercial uses for atomic energy.11/

With the twin energy shocks of the 1970s, the Congress broadened the mandate of these national labs so that they could focus on a broader range of issues, including conservation and alternative energy sources. In 1975, in the wake of the oil embargo, the Congress created the Department of Energy and transferred control of the labs to the newly created department.

The reason for the broadened responsibilities of the labs was that the Congress, along with Presidents Ford and Carter, believed that the market did not give the private sector sufficient incentives to undertake the needed energy research. A number of factors seemed to justify extraordinary efforts. In the first place, the decision to regulate prices of domestic crude oil and refined products arguably diminished private industry's incentives to undertake this research. Moreover, because the United States relied heavily on foreign sources of oil, it

11. See, for example, G. Eads and R. Nelson, "Government Support of Advanced Civilian Technology: Power Reactors and the Supersonic Transport," *Public Policy* (Summer 1971), pp.405-427.

faced the continued threat that its supply would again be disrupted for political reasons. Finally, some argued that the large risks and enormous costs of development in these areas further justified government involvement.

Consequently, the government increased its real expenditures for civilian energy R&D by an average of 20 percent a year between fiscal years 1974 and 1980, virtually tripling the amount during the period.12/ Efforts included, but were by no means limited to, the development of breeder reactors, synthetic fuels, solar power, thermal energy, and improving the internal combustion engine. Many of these efforts went well beyond basic or even applied research and involved developing new products and processes. In fact, development was the most rapidly growing part of the government's energy R&D.

The Reagan Administration significantly reduced government efforts to design new products and processes that conserve energy and instead focused DOE's efforts on more basic and generic research. Budget obligations for development projects at DOE decreased by 40 percent between fiscal years 1980 and 1985, with obligations for civilian development falling much more rapidly.13/ In the meanwhile, obligations for basic research at DOE increased by more than 30 percent.

Other Nondefense Programs. Health and general sciences were among the handful of budget functions that registered an increase in real R&D expenditures during the 1980s.14/ General sciences largely consist of grants from the National Science Foundation to colleges and universities for basic research (see Table 2). This is the type of research that the private sector has the least incentive to undertake,

12. The expanding R&D effort was a factor in the decision to establish the Department of Energy. During the Ford Administration, the Congress transferred the research facilities of the Atomic Energy Commission to the Energy Research and Development Administration in the Department of Commerce. The Department of Energy assumed these functions after it was established during the Carter Administration.

13. The National Science Foundation does not report expenditures on basic and applied research and development by budget function. Rather, it reports data on obligations by department or agency. Recall that a substantial portion of the DOE's R&D activities relate to the military.

14. Expenditures for R&D in agriculture, which account for about 2 percent of the government's R&D budget, also experienced real growth during this period. Since these expenditures have little influence on domestic manufacturing, they are not discussed here.

and the kind that the Reagan Administration has emphasized. Between fiscal years 1981 and 1987, real expenditures for general sciences increased at an average annual rate of 3.3 percent. Yet, this represented an increase of only one-third the rate at which R&D for defense increased during that period.

Funding for health research, most notably by the National Institutes of Health (NIH), increased at an average annual rate of a little more than 5 percent during the 1980s. Coupled with the decline in energy research, this increase made health the second largest category receiving federal R&D support.15/ As in the case of general sciences, private firms generally do not have much incentive to undertake the types of projects financed by NIH. Thus, the increase was consistent with the Reagan Administration's R&D objectives of emphasizing projects that tend to be neglected by the private sector.

With the shift in government funding toward basic and generic research, there has been a corresponding decline in resources devoted to developing nondefense products and processes. Excluding the Department of Defense, the government's obligations for development declined by nearly 40 percent between 1980 and 1985.16/ In addition, each of the principal nondefense agencies sponsoring R&D significantly reduced its funding of development. Real obligations for development by the Department of Defense, however, grew by more than 80 percent during this period.

At the same time, real obligations for basic research by nondefense agencies increased by more than 40 percent, with each of the six principal R&D agencies registering increases. In the meanwhile, the share of nondefense R&D for basic research increased from 27 percent to 37 percent. Consequently, development accounted for more than 40 percent of nondefense R&D obligations in 1980, but less than 30 percent in 1985.

15. Expenditures for space R&D, which had been the second largest R&D function in the early 1970s, contracted by 25 percent a year between 1981 and 1987.

16. Unlike the data on total R&D, these data are for fiscal year obligations by agency and not function. Actual spending by agency could be more or less than the obligations they incurred in a given fiscal year.

Defense R&D. Currently, the Department of Defense accounts for about two-thirds of the government's R&D expenditures; it accounted for about 50 percent of the R&D efforts for much of the 1970s. The military's goal in funding R&D is primarily to develop new weapons

TABLE 2. FEDERAL OBLIGATIONS FOR TOTAL RESEARCH AND DEVELOPMENT BY AGENCY, PERFORMER, AND TYPE OF RESEARCH FOR FISCAL YEAR 1975

	Total (In millions of dollars)	Percentage of Agency R&D, by Type		
		Basic Research	Applied Research	Development
Departments				
Agriculture	943.0	46.9	49.7	3.4
Commerce	398.8	5.5	76.4	18.1
Defense	29,791.5	2.7	7.2	90.1
Energy	4,966.0	18.9	25.2	55.9
Health and Human Services	5,451.0	59.2	33.2	7.6
Interior	391.7	33.3	61.6	5.1
Transportation	401.6	0.6	17.5	81.9
Other Agencies				
Environmental Protection Agency	320.4	11.8	54.0	34.2
National Aeronautics and Space Administration	3,327.2	23.5	25.7	50.8
National Science Foundation	1,345.6	94.1	5.9	--
Total, All Agencies a/	48,332.3	15.7	16.4	67.9

SOURCE: Congressional Budget Office using data supplied by the National Science Foundation.

a. Only departments and agencies with more than 0.5 percent of total government expenditures are listed separately.

(Continued)

systems that it will ultimately procure. For the most part, the private firms that produce the weapons perform the research.

The Department of Defense has always devoted a commanding share of its R&D efforts to development, and because of the arms

TABLE 2. (Continued)

	Percentage of Agency R&D, by Performers				
	Intra-mural b/	Indus-trial Firms	Universities and Colleges	FFRDCs c/	Other d/
Departments					
Agriculture	66.6	0.6	31.1	0.0	1.7
Commerce	70.1	9.5	13.2	0.5	6.8
Defense	27.9	63.6	3.2	3.3	2.0
Energy	4.5	16.1	7.2	70.8	1.4
Health and Human Services	22.0	3.3	57.7	1.0	15.8
Interior	87.4	1.5	8.7	1.5	1.0
Transportation	34.3	51.1	1.9	3.0	9.5
Other Agencies					
Environmental Protection Agency	32.6	38.9	18.7	0.2	9.6
National Aeronautics and Space Administration	35.2	47.4	7.7	7.0	2.8
National Science Foundation	10.6	3.1	74.5	6.4	5.4
Total, All Agencies a/	26.9	45.5	13.0	10.4	4.2

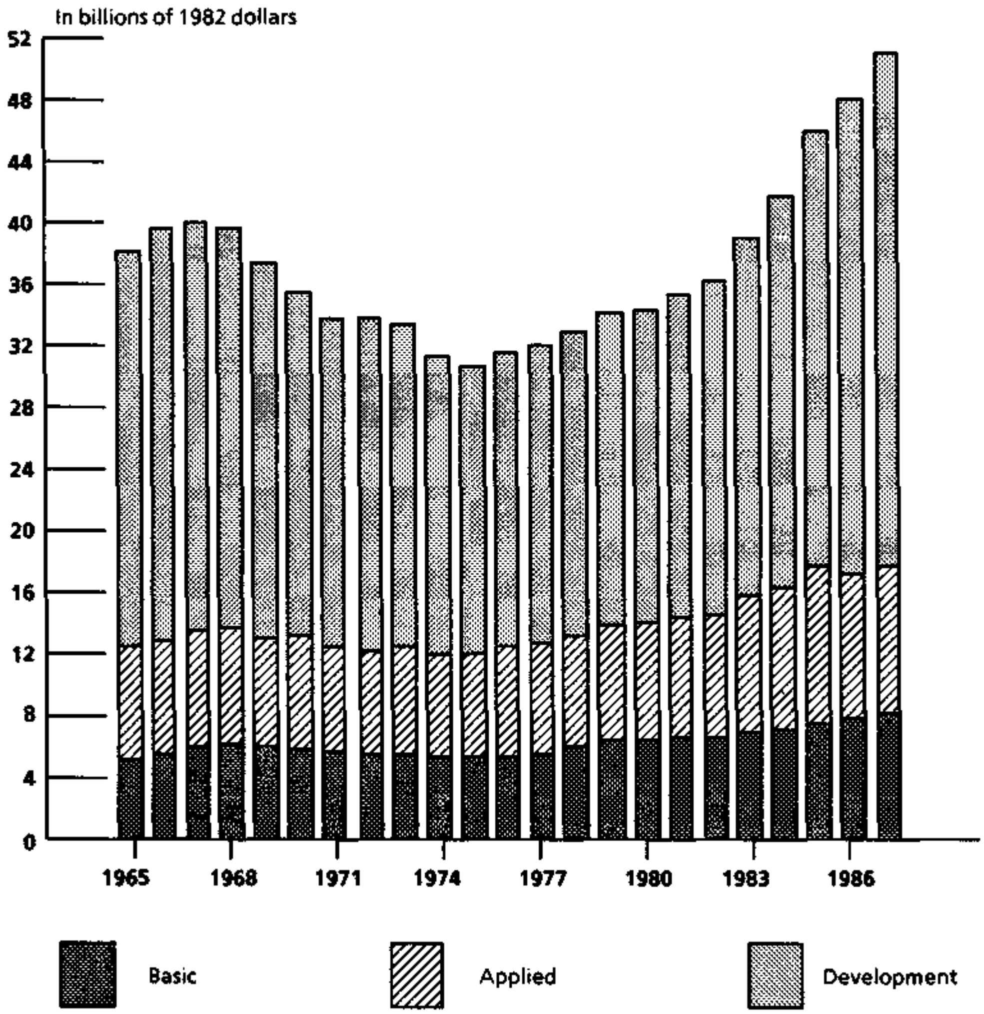
b. Performed in government facilities by government employees.

c. Federally funded research and development centers are administered by universities, colleges, and private firms.

d. Includes research performed by nonprofit organizations, state and local governments, and foreign countries.

buildup during the 1980s, this share is approaching 90 percent. Thus, despite the decreased emphasis on development by nondefense agencies, the growth of defense expenditures has meant that develop-ment accounts for a large portion of the government's R&D budget. Its share has grown from 59 percent of R&D expenditures in 1980 to more than 63 percent in 1985 (see Figure 7).

Figure 7.
Federal Research and Development Expenditures (By type)



SOURCE: Congressional Budget Office using data supplied by the National Science Foundation.

The government performs only a quarter of the R&D it funds, although another 10 percent is performed in government-owned labs operated by private contractors. On the other hand, industry performs nearly half of government-funded R&D, with the Department of Defense and NASA accounting for over 90 percent of the expenditures. In 1984, more than 80 percent of the federal R&D funds that went to industry was used for development.17/ In contrast, private firms used 72 percent of their own R&D funds for development (see Figure 8). Despite the tendency of private firms to concentrate their efforts on development, they provide proportionately more support for industrial basic and applied research than the government does.

PRIVATE SECTOR SUPPORT OF R&D

Between 1975 and 1984, real R&D expenditures in the private sector grew at a rate of more than 6 percent a year, nearly double the average annual rate of increase between 1965 and 1975. Between 1984 and 1987, the growth rate of real industrial spending on R&D fell to roughly 3 percent a year. Moreover, in a reversal of a trend established in the previous decade, the composition of the R&D funded by the private sector has changed somewhat during the 1980s.

A common view of the innovative process is that firms in the private sector devote too much of their efforts to projects aimed at producing immediate commercial returns. Between 1975 and 1980, firms placed increased emphasis on development, which generally represents efforts that provide the most immediate returns. Between 1980 and 1987, however, industry expenditures on research and most notably basic research have been increasing more rapidly. In fact, industry funding of basic research increased at an average annual rate of 8 percent during this period.

Nevertheless, domestic industry spent a smaller proportion of its R&D budget on both basic and applied research in 1985 than it did in 1965. The shares of both reached a minimum in 1980 and have subse-

17. Because government support of private industry's basic and applied research has increased more rapidly than its support of development, this percentage has declined somewhat since 1980.

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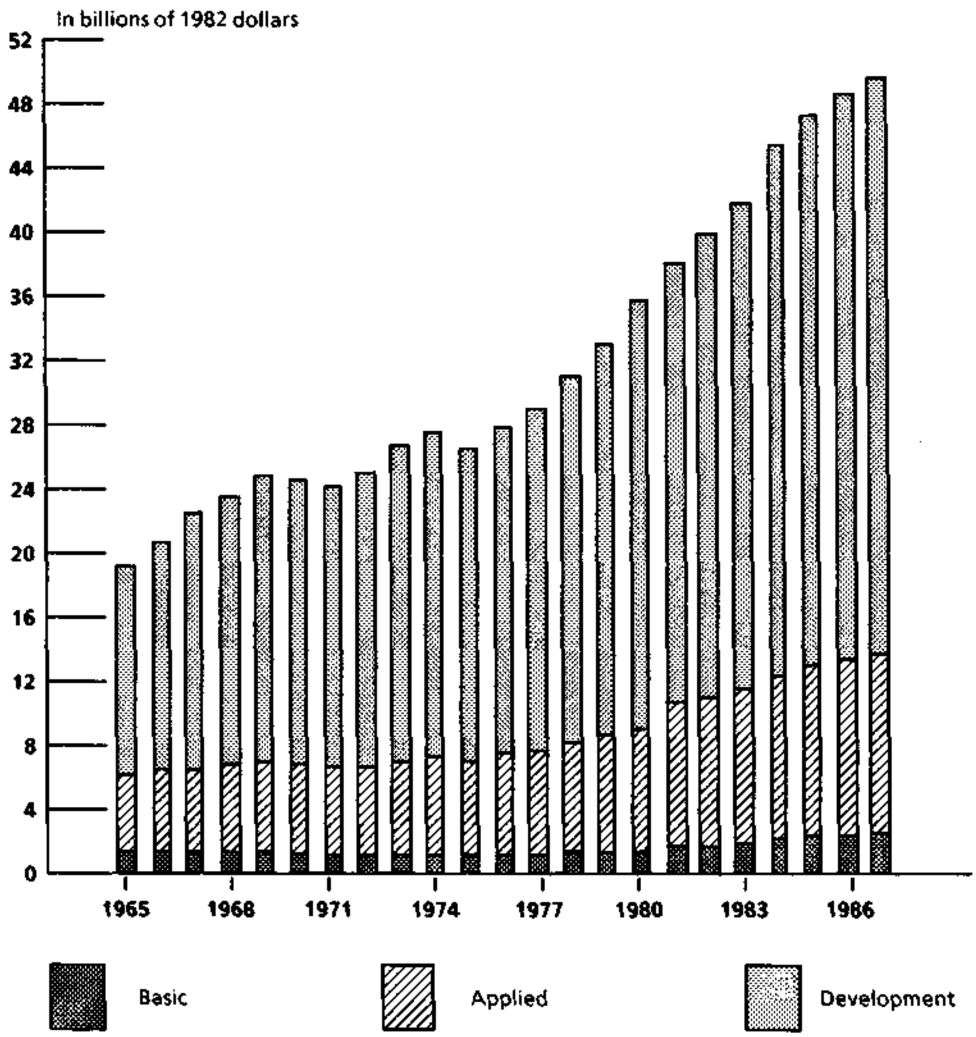
quently recovered somewhat. In 1965, industry devoted 7 percent of its R&D budget to basic research, and in 1987 it devoted 5 percent. Similarly, the 23 percent of R&D going to applied research was two percentage points lower than its share in 1965.

Figure 8.
Industry Research and Development Expenditures (By type)



SOURCE: Congressional Budget Office using data supplied by the National Science Foundation.

At the same time that U.S. manufacturers have tended to stress research with short-run payoffs, they have also stressed efforts to make new products rather than new processes. A recent study found that U.S. manufacturers devoted only a third of their R&D to process innovations.18/ In comparison, Japanese manufacturers, who have developed the reputation for efficiency, spent two-thirds of their R&D budget on process innovations. This amount is consistent with the frequently offered view that Japan's success is based on more efficiently producing products that have been developed elsewhere. Moreover, despite the ample discussion of declining U.S. competitiveness, this same study found that domestic firms are not placing more emphasis on developing process technologies. Over the last 10 years, the proportion of R&D that they devote to new production processes has remained essentially unchanged.

In keeping with its reputation as an imitator, the Japanese are apparently much more efficient than domestic firms in introducing products that incorporate existing technologies. For example, one study concluded that Japanese firms take about 25 percent less time and spend about 50 percent less money than U.S. firms in making innovations that rely on technologies developed externally to the firm--that is, in imitating.19/ Moreover, when imitating, Japanese firms tend to place greater emphasis on development and on steps to reduce productions costs than domestic firms. In contrast, U.S. firms place greater emphasis on marketing than do Japanese firms. The study did not, however, find significant differences between domestic and Japanese firms in the cost and time of innovating when internal technologies were used.

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18. The study was based on 50 Japanese firms selected at random in the chemical, electrical equipment, instrument, machinery, rubber, and metals industries. For each Japanese firm, a domestic firm of about the same size in the same industry was selected. See Edwin Mansfield, "Industrial R and D in Japan and the United States: A Comparative Study," *American Economic Review*, May 1988 (forthcoming).

19. See Edwin Mansfield, "The Speed and Cost of Industrial Innovation in Japan and the United States: External vs. Internal Technology," *Management Science*, forthcoming.

CHAPTER III

GOVERNMENT R&D EFFORTS

Although the government has played a critical role in the nation's R&D efforts, it has not been by design. Rather, the government has funded a variety of R&D programs, each with its own specific purpose. The sum of these individual programs has largely shaped the government's policies. The federal government's efforts generally fall into one of the following categories:

- *Creating new products that the government ultimately procures.* The Department of Defense is the major sponsor of these efforts, which are far and away the principal R&D activities of the government.

- *Supporting R&D that the private sector has only limited incentives to perform.* In addition to basic research, this includes health-related issues, such as the effects of diet and treatment of particular diseases. Much of this research is performed in colleges and universities, and so these efforts also indirectly support education.

- *Speeding the rate of innovation by private firms because of government expertise or national policy objectives.* This has been the rationale for much of the government's support of energy research. The Congress, however, has substantially reduced its funding of such projects under the Reagan Administration.

- *Explicitly providing aid to R&D efforts in the private sector.* The National Bureau of Standards has assisted numerous domestic industries by developing new measurement standards as well as new measurement techniques. More recently, the federal government has provided more direct aid to firms by partially funding research centers at a number of universities. Few of the government's R&D activities, however, fall under this category.

Although the government devotes little effort to aiding private firms directly, in a number of instances government-supported R&D has had substantial commercial consequences. This chapter considers the reasons why these programs have produced such far-reaching effects, while others have not. It also considers a number of other programs--such as patents and tax subsidies--that the Congress has adopted to encourage the creation of new products and processes by the private sector.

HOW GOVERNMENT POLICIES AFFECT INNOVATION IN THE PRIVATE SECTOR

While it has not been a primary goal, government-supported R&D has significantly influenced the competitiveness of domestic industry. For example, R&D that was performed in response to government procurement led to a more rapid commercial development of the jet aircraft, the integrated circuit, and the computer. Government support of research in genetics also helped launch the biotechnology industry. Yet, even in these cases, potential commercial applications were not central to the government's funding decisions. In fact, the National Bureau of Standards (NBS) of the Department of Commerce, with an annual budget of less than $200 million, is the only government agency whose principal mission is improving the competitiveness of domestic industry.1/

In considering actions the Congress could take to increase the innovativeness of domestic industry, it is instructive to consider the impact that various types of government programs have had. Of course, the nature of the technology being developed is enormously important. Some projects are so specialized--developing a particular nuclear warhead, for example--that any commercial applications are unlikely. But even among projects with the same commercial potential, differences in the speed and the cost at which commercial innovations are developed can be considerable.

1. There are other cases--the National Aeronautics and Space Administration, for example--where aiding the private sector is an explicit goal of government-supported research.

To appreciate these differences, it is necessary to consider the innovative process. Dividing R&D into basic research, applied research, and development suggests that the innovative process is a pipeline. In this view, an idea for a new product or process emerges during basic research; then during applied research the firm gains further insights, and ultimately, after a prototype is developed, the idea emerges as a final product. Yet, the innovation process is rarely so straightforward.

In fact, ideas for one invention can often come from the pursuit of an entirely different goal. In trying to overcome a technological or scientific hurdle, firms often pursue a variety of different R&D activities simultaneously. The more approaches a firm uses to solve a problem, the more rapidly it is apt to find a solution.2/ Also, unsuccessful approaches often provide useful insights and thereby aid the quest for a solution. Thus, firms generally find it efficient to perform basic research, applied research, and development simultaneously.

Moreover, innovations are not simply a product of new discoveries in science and engineering; changes in demand also play a critical role. A new technology would not lead to a new product if firms envisioned little demand for it. Conversely, the perception of demand for a new product can precipitate the search for a new technology.

If the pipeline analogy described the creation of innovations, the government's role in the process would be straightforward. The government would have its greatest impact by supporting basic research, the type of research that firms are most reluctant to undertake. Increased support of such efforts would have a direct and positive effect on the innovative output of domestic firms.

Yet, it is questionable how large an impact increased government support for research would have, in and of itself, on the innovative activity of the private sector. The most promising research findings will not lead to commercial innovations if the private sector is unaware of them. Furthermore, simply having knowledge about the results of government-sponsored research may not be enough to assure that the results will be properly used. Given the fluidity surrounding the research process, good lines of communication between

2. See, F.M. Scherer, "Research and Development Resource Allocation under Rivalry," *Quarterly Journal of Economics* (August 1986), pp.359-394.

those performing the research and those developing the applicable commercial innovation are extremely valuable.3/

Of course, science and technology are only part of the innovative process. The best science will not yield successful commercial applications unless the resulting product is attractive to an identifiable set of consumers. While the government can, and to a considerable extent already does, maintain the talent necessary to evaluate science, it has virtually no experience in the manufacture and sale of products. It is simply not qualified to determine the commercial feasibility of the research it funds. Thus, decisions about developing and marketing new products and processes should be left largely to the private sector.

Finally, the government should not sponsor R&D that the private sector would otherwise perform. The government's commitment to R&D is largely based on the premise that, left to their own devices, firms would underinvest in research and development. Moreover, this underinvestment would take place in certain identifiable areas. Effective government programs would address those areas. They should also encourage additional private sector R&D efforts and not redirect existing research efforts or support research that firms would have funded in any case.4/

To summarize those government programs that meet the following criteria, all other things being equal, can be expected to have the greatest impact on the innovative process: (1) knowledge by the potential users of the relevant research; (2) good lines of communication between those performing the research and those developing the commercial innovations; (3) decisions to develop and market new products and processes remain with the private sector; and, (4) encouragement of additional R&D efforts by the private sector.

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3. Roland W. Schmitt, "National R&D Policy: An Industrial Perspective," *Science* (June 15, 1984), pp. 1206-1209.

4. A government program that led firms to redirect their research efforts to more highly valued efforts, however, would be beneficial. But firms are generally better than the government at gauging the value of alternative projects.

GAUGING THE IMPACT OF FEDERAL R&D PROGRAMS

Because the U.S. work force is relatively skilled and relatively high-paid, domestic firms tend to compete most successfully in high-technology industries--that is, industries whose products or processes incorporate significant advances in science and engineering. The government plays a role in the innovative process both by supporting a substantial share of the nation's R&D and by encouraging private sector efforts.

Federal Procurement

Of all the federal R&D programs, federal procurement policies have had the greatest commercial impact. One important reason for this impact is sheer volume--developing products that it will ultimately purchase accounts for the bulk of the government's R&D expenditures. These procurement activities have had a substantial impact on a number of industries.

Distribution of Funds to Industry. As previously noted, the government's R&D expenditures to industry are largely used to develop new products for the military, although the space program also plays a significant role.5/ Accordingly, more than half--in 1984, it was 56 percent--of the government expenditures for R&D by industry go to aerospace manufacturers.

Largely because of aerospace, a disproportionate share of the government's research and development funds goes to high-technology industries. While firms in these industries account for 52 percent of company funds spent on industrial research and development, they receive 80 percent of all federal expenditures for R&D that go to industry. In fact, the government accounts for three-fourths of the R&D performed by aircraft and missile producers (see Table 3). For the rest of manufacturing, the government's share is only 18 percent.

5. In fiscal year 1987, DoD accounted for 86 percent and NASA accounted for 7.2 percent of the federal government's support of industrial R&D.

TABLE 3. GOVERNMENT SUPPORT OF RESEARCH AND DEVELOPMENT BY INDUSTRY, 1984 (In percents)

Industry	Share of R&D Performed by Industry That Is Funded by the Government	Share of Total R&D Performed by Industry: Supported with Company Funds	Share of Total R&D Performed by Industry: Supported with Government Funds
Low Technology			
Food and Kindred Products a/	0.0	1.2	0.0
Textiles and Apparel a/	0.0	0.2	0.0
Wood Products and Furniture	0.0	0.3	0.0
Petroleum a/	8.1	3.5	0.9
Primary Metals	32.5	1.6	1.6
Other Transport Equipment a/	37.8	0.4	0.4
Other Manufacturing a/	5.3	0.9	0.1
Subtotal	12.3	8.0	3.1
Medium Technology			
Paper and Allied Products a/	0.0	1.1	0.0
Chemicals and Allied Products a/	4.7	6.8	1.0
Rubber Products a/	0.0	1.2	0.0
Stone, Clay, and Glass Products a/	0.0	0.7	0.0
Fabricated Metal Products	8.1	1.1	0.3
Machinery, Nonelectrical a/	11.2	3.8	1.3
Electrical Equipment	48.1	7.3	11.1
Motor Vehicles	11.1	8.9	3.1
Subtotal	17.2	31.3	16.8
High Technology			
Drugs and Medicines a/	0.1	5.0	0.0
Office and Computing Machines a/	13.1	10.4	4.3
Communication Equipment	40.5	11.3	14.5
Electronic Components	18.5	3.6	2.1
Aircraft and Missiles	75.4	23.6	56.1
Professional and Scientific Instruments	13.4	7.2	3.1
Subtotal	41.5	61.0	80.1
Total	31.9 b/	100.0	100.0

SOURCE: Congressional Budget Office using National Science Foundation data.

NOTE: Columns may not add to totals because of rounding.

a. Federal research and development expenditures estimated by the Congressional Budget Office.

b. This figure represents the share of the total R&D performed by all industries that is funded by the federal government.

Excluding the aerospace industry, however, government spending only slightly favors high-technology industries. Firms in other high-technology industries account for 48 percent of privately financed R&D, but receive 55 percent of government funds. Correspondingly, the proportion of government R&D expenditures that firms in both low- and medium-technology industries receive is smaller than their share of private R&D expenditures.

Notably, one high-technology industry--pharmaceutical manufacturers--receives less than 1 percent of its research and development resources from the federal government. The pharmaceutical industry, however, receives substantial benefits from research financed by both the National Institutes of Health and the National Science Foundation. Much of this involves research into areas like biochemistry, pharmacology, and particular diseases that have direct applications to the development of new drugs. Moreover, patents provide more protection for new pharmaceuticals than they provide for inventions in most other industries.

High-technology industries--those that spend a relatively high proportion of their sales on R&D--have grown more rapidly than other industries and have had more favorable balances of trade (see the Appendix). These are the same industries that receive the bulk of the government's support of R&D in industry. In fact, aircraft and missile manufacturers, which receive over half of the federal R&D expenditures to industry, represent one of the few industries whose trade balance increased between 1980 and 1985. Many of these industries' exports, however, are not commercial products in the usual sense. Rather, they are sales of military equipment to foreign governments.

Impact on Commercial Markets. In numerous instances, products developed for the government have helped spawn significant commercial innovations. It would probably be a mistake, however, to conclude that government R&D significantly increased the number of commercial products introduced in the affected industries. Rather, it is more likely that government procurement sped up the rate at which these products were introduced. For the most part, the private sector initiates the ideas for the R&D projects that the government supports, and the government has largely supported evolutionary--not revolutionary--innovations.

Government R&D does, however, increase the likelihood that the new products will be introduced by a domestic firm. Being first in the market with a particular product can have a lasting effect on international competitiveness. By spurring the growth of domestic industries, federal R&D can help provide U.S. firms with the requisite skills and knowledge to design and build future generations of the product.7/ This head start may also enable domestic firms to achieve production economies more rapidly, which may be a factor in the relative success of domestic firms that both compete in high-technology industries and perform a substantial amount of government-sponsored R&D.

The ability of firms to remain leaders in world markets, however, often depends on the nature of the product. For example, if equipment manufacturers rapidly develop a standardized manufacturing process, then the ability to produce the innovation may be quickly disseminated throughout the world.8/ Moreover, some argue that the advantages to a firm of being first in a market with a particular product are overrated, because the initial products are often not well-designed.9/

Of course, most R&D related to procurement does not spawn commercial products. Much of it simply does not have civilian applications. Moreover, a lot of these efforts do not seek to uncover a new technology, but rather modify an existing product for a narrow and specific task. Yet, a number of projects, while incremental in nature, have required fundamental advances. For the most part, these involve substantial risks--that is, the payoffs to the R&D are uncertain and can only be realized in the long run. These are precisely the kinds of projects that private firms are most reluctant to undertake. In those cases where the technologies have had commercial applications, government procurement has provided enormous aid to domestic manu-

7. For a discussion of the role of government research and development in these and other industries, see R. Nelson, ed., *Government and Technical Progress: A Cross-Industry Analysis* (New York: Pergamon Press, 1982). Also see Kenneth Flamm, *Targeting the Computer* (Washington, D.C.: The Brookings Institution, 1987).

8. See, for example, James Utterback, "Innovation and Industrial Evolution in Manufacturing Industries," in Bruce Guile and Harvey Brooks, eds., *Technology and Global Industry* (Washington, D.C.: National Academy Press, 1987), pp.16-45. Also see David Teece, "Profiting from Technological Innovation: Implications for Integration, Collaboration, Licensing, and Public Policy," in David Teece, ed., *The Competitive Challenge* (Cambridge, Mass.: Ballinger, 1987), pp. 185-219.

9. See N. Rosenberg and W. Steinmueller, "Why Are Americans Such Poor Imitators?" Stanford University, unpublished paper, December 21, 1987.

facturers. In this respect, government procurement satisfies one of the four criteria for successful government R&D programs--it encourages innovative activities that firms would not otherwise undertake.

Procurement also satisfies the other three criteria as well. First, since firms perform the requisite R&D under contract to the government, they are obviously aware of the results. Because the government may have contracts with a number of firms when pursuing a promising research area, the results are sometimes widely disseminated. Second, private firms have substantial incentives to assure effective communication between the scientists and engineers performing the government-sponsored R&D and those developing commercial applications. In fact, some of the same people might be involved. Finally, although the government underwrites the development of the original product, the firm is completely responsible for the development of any related commercial civilian products.

Government Support of Basic Research

As previously noted, private firms generally concentrate their R&D resources on projects whose outcomes are predictable and whose payoffs occur relatively quickly. From society's perspective, therefore, firms probably spend too little on research when a lot of uncertainty surrounds the commercial payoffs and especially on research without any specific commercial objectives--that is, on basic research. But in laying the groundwork for innovations relying on advanced technologies, government-financed basic research influences the R&D of firms only indirectly.

Where the Funds Go. The federal government funds 65 percent of the nation's basic research, but industry receives only 7 percent of these outlays. Largely because of support from NSF and NIH, academics receive roughly half. The federal government, including contractor-operated government labs, perform about 35 percent of federally funded basic research.

Evaluating the Commercial Impact. The government supports basic research in order to expand the stock of knowledge. This research can lead to commercial innovations, however, when firms can use the findings to develop new products or processes. But generally a number of factors limit the impact of federally supported basic research on industrial competitiveness.

In the first place, scientists and engineers employed by firms are often unaware of the results of the basic research. The research is generally performed in university or government laboratories, with findings presented in professional journals and at professional meetings. Scientists and engineers employed by firms to do applied research often find it difficult to keep fully abreast of these new findings. This is less likely to occur, however, in those firms that maintain an active basic research program.10/ On the other hand, word of truly revolutionary findings--high-temperature superconductors, for example--travels rapidly and applied researchers will quickly learn about them.

Another problem is that, since firms account for a relatively small percentage of the basic research performed in the economy, the lines of communication between the people performing the research and those developing new products are generally not well developed.

These difficulties can be overcome in a number of ways. For one thing, firms can develop effective lines of communication by contracting with professors who either have made the relevant discoveries or work in the area. Such arrangements have proved to be especially helpful in disseminating basic research findings in biotechnology, which is rapidly emerging as an important industry.11/ In addition, a number of university professors have played a major role in commercializing the results of their research by either joining existing firms or forming start-up companies. While researchers in government laboratories have similarly entered the private sector, they do not have the same flexibility to consult with interested firms.

On the other hand, government support of basic research satisfies the remaining two criteria. First, private firms that draw government-sponsored basic research have complete responsibility for intro-

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10. One study found a positive relationship between the amount of basic R&D that firms did and their growth in productivity. The author suggests that firms are likely to use basic research results for which they are responsible as an explanation for the finding. See Edwin Mansfield, "Basic Research and Productivity Increase," *American Economic Review* (December 1980), pp.863-873.

11. For a critical discussion of these growing links between industry and universities, see Martin Kenny, *Biotechnology: The University-Industrial Complex* (New Haven: Yale University Press, 1986).

ducing commercial products and bear most of the cost of innovating. Second, since firms devote such a small proportion of their resources to basic research, federally supported basic research is unlikely to substitute for R&D that firms would otherwise perform.

While U.S. government support of basic research clearly provides some important aid to domestic firms, foreign firms receive essentially the same benefits. Foreign scientists, like their domestic counterparts, have access to the professional journals and meetings where the research results are presented. Foreign firms are also free to contract with university professors. In fact, the ease of disseminating basic research results is best exemplified by recent complaints that the Japanese government has not been funding enough basic research.12/

Perhaps even more important than the direct benefits of government support of basic research--that is, innovations flowing directly from the research--are the indirect benefits. The principal benefit is that government support of basic research in universities and colleges increases the quality of the scientists and engineers in the domestic work force--that is, university research has a positive effect on the education provided by U.S. institutions. In the first place, it expands the knowledge of researchers. In addition, it helps attract more highly qualified professionals to positions as teachers at colleges and universities. The prospect of receiving financial support to do research not only supplements university salaries, but it also enables university professors to pursue subject matters of interest to them.13/

Meeting Market Needs

The government also pursues R&D with direct commercial or practical applications when it perceives that the market does not provide firms with sufficient incentives. For the most part, these activities--like much of the government-sponsored health research--do not in-

12. See, for example, "Japanese Launch Bid to Lead the World in Pure Science," *The Wall Street Journal*, June 3, 1987, p.16.

13. In 1986, 32 percent of graduate students in science and engineering doctoral programs, excluding social science programs, in U.S. colleges and universities were foreign nationals. This percentage is increasing. The value of the education that foreign nationals receive, however, is lost to the U.S. economy if they return home.

volve substantial commercial applications. On the other hand, in a number of instances--most notably those involving energy--the primary goal of funding research and development was to generate commercial applications. Most of these efforts, however, have not been very successful.

Health. The public clearly values health. Accordingly, the returns to developing a successful drug can be enormous. Other areas of health-related research are also quite beneficial, but do not offer the potential of similar gains. For example, conducting a study on the effect of diet or exercise on the incidence of disease can be quite costly and provide only limited commercial return. Such studies, however, have implications for many more products than any particular firm produces. Thus, the public benefit from such a study far exceeds the gains to any particular firm.14/

The government--specifically NIH--also devotes substantial resources to determining the proper methods for treating particular diseases. While private firms have incentives to develop drugs or equipment, they have less incentive to evaluate the effectiveness of different treatments or to develop new clinical methods. In some cases, however, these efforts produce equipment that the private sector can manufacture and market commercially. In addition, research supported by the National Cancer Institute seeks to develop drugs that are effective in the treatment of cancer. Even more significantly, NIH supports a substantial amount of basic research that has pioneered significant advances in the pharmaceutical industry.

Energy. The oil embargo in the mid-1970s encouraged the government to develop alternative sources of energy and new conservation methods. For the most part, these efforts were not successful, and the Congress--agreeing with the Reagan Administration--dramatically reduced government expenditures for civilian energy R&D. With the decline in oil prices after 1981, the "energy crisis" essentially ended.

The method by which the government supported energy research may have contributed to the dearth of significant innovations that

14. Numerous nonhealth issues share similar characteristics. The private sector has limited incentives to do research on weather forecasting, environmental issues, space, oceans, and the earth itself.

these programs produced. Although the government attempted to develop new products and processes that would be commercially viable, in many cases scientists and engineers employed in the private sector did not have an effective role in designing projects intended to have direct applications to their industries. Moreover, the performance of much of the research as well as the construction of the various demonstration plants required little financial contribution by firms in the private sector. In fact, a lot of the research aimed at producing commercial innovations was conducted in government laboratories that had virtually no experience in such activities. As illustrated by the synfuels project, the government is more apt than the private sector to attempt to commercialize products and processes prematurely.

In responding to the energy crisis, the government did not meet the previously enumerated criteria for government programs that successfully stimulate commercial innovation. While scientists and engineers in private industry may have been aware of the research being conducted in government-owned labs, researchers in the private and public sectors failed, for the most part, to establish close working relations. Moreover, in constructing demonstration plants, the government was essentially making commercial decisions. Finally, firms in the private sector tended to conduct their R&D activities independently of these government efforts, and thus the government programs probably did not stimulate much additional activity.15/

Direct Government Support

There are a few examples where the primary aim of government R&D has been to increase the competitiveness of domestic industry. This has been an objective of the National Bureau of Standards (NBS) since its creation in 1901. More recently, the government and industry have jointly funded a number of research centers that aim to help domestic manufacturers by developing generic technologies. Finally, the Congress recently decided to fund--jointly with 12 firms--Sema-

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15. The Department of Energy also supported some R&D by industry. A study, financed by the National Science Foundation, concluded that company-financed R&D increased in response to increased support of R&D by industry. See Edwin Mansfield, "Studies of Federally Funded Research and Development, Market Structure, and International Technology Transfer: A Final Report," NSF, unpublished paper, undated.

tech, a five-year effort to develop new techniques to manufacture semiconductors.

The National Bureau of Standards. Developing standards of measurement and creating measurement techniques provide important benefits to domestic manufacturers. Proper measurement allows firms to design products and production processes so that raw materials can be used most effectively. In addition, being able to measure the chemical and physical reactions during the production process can lead to higher-quality products. For example, NBS has been working with steel companies in developing new ways of measuring the internal temperatures of molten steel during the production process. Such improved measurement techniques should enable firms to improve the quality of the steel they produce. NBS has traditionally maintained close contact with scientists and engineers in the private sector, and much of its research involves technologies that can be used in a variety of industries.

Standards also enable different firms to manufacture products that are compatible with one another. For example, NBS has recently established the Automated Manufacturing Research Facility. This facility helps firms learn how they can automate their operations and develop standards so that various capital equipment manufacturers can design compatible machinery.

NBS largely satisfies the four criteria for successful government input into the innovative process. Potential users are aware of the research. Good lines of communication exist between researchers and firms. Commercial implementation is left to the private sector. Finally, since the research at NBS largely complements the research done in the private sector, it encourages private sector initiatives. For example, developing standards that make machines more compatible will encourage firms to develop new capital equipment products. Similarly, developing new methods of measuring materials encourages firms to use these findings to create new quality control devices.

Engineering Research Centers. The Engineering Research Centers (ERCs) are partnerships among the government, private firms, and universities committed to increasing innovativeness. For example, ERCs have been established in fields such as robotics, biotechnology processes, and material engineering. The National Science Foundation administers the program. The ERCs are multidisciplinary centers that are located on university campuses, with the government and private firms providing the financial support. As a center becomes established, however, the government will gradually withdraw its financial support.

Although nominally under university control, the corporate sponsors undoubtedly play an important role in developing the agendas for the centers. Their support is critical to each center's continued existence. Currently, there are 12 Engineering Research Centers. Since these centers only began being established in the mid-1980s, it is still premature to draw a conclusion about their accomplishments. The Reagan Administration is sufficiently confident about the concept that it has proposed the establishment of Science and Technology Research Centers that will operate quite similarly to the ERCs. While the ERCs stress engineering research, the new program will concentrate on science.

The Engineering Research Centers clearly satisfy all the criteria for a successful government program. Since they involve newly established institutes and a variety of different firms, the research program is likely to diverge from any given firm's agenda. Moreover, if the program does yield useful results, it will stimulate development activity by the sponsoring firms. Thus, the results will be disseminated much more widely than would have been the case if only one firm had funded the research. Finally, the sponsoring firms clearly know of the research being done at the ERCs and have the opportunity to work closely with the employees at the centers.

Sematech. The Congress has recently decided to fund--jointly with a consortium of semiconductor and capital equipment manufacturers--Sematech. Sematech is a research center whose primary goal is to develop more efficient methods of manufacturing semiconductors. Both Sematech and the Engineering Research Centers involve the federal government and a group of private firms jointly funding a research center. There are, however, three noteworthy differences. First, in the case of Sematech, the firms, rather than the government or a university, promulgated the idea. Second, Sematech is not limited to a university. Finally, the cost of Sematech is an order of magnitude larger than the largest ERC.16/ Also noteworthy is that Sematech, which is attempting to develop specific technologies for a specific industry, has a much more explicit mandate than many of the Engineering Research Centers.

Government Programs to Encourage Private Sector Innovation

The government has developed a number of programs increasing the innovative efforts of the private sector, but they involve no government R&D outlays.17/ Some of them--such as the grant of a patent--increase the expected profits from producing an innovation. Others--such as tax credits for R&D--reduce the cost of innovating. In both cases, however, the government has designed these programs to increase the profitability of innovative activities.

Of the four criteria for evaluating government R&D programs, only one is relevant here--the magnitude and the nature of the private R&D that a government program stimulates. The other three--knowledge of the research, good lines of communication, and financial exposure--clearly do not apply.

For the most part these programs have encouraged innovative activities at only modest cost to the government. Yet, the benefits are not always as substantial as they may appear. Some of these programs have not generated much additional R&D, while some of the R&D that is encouraged may have limited social benefit.

Patents. The grant of a patent gives an inventor a monopoly on his or her invention for 17 years. Because it increases the expected profits of a new product or process, the prospect of obtaining a patent encourages firms and individuals to engage in innovative activities.

Society values innovation because it creates new products and reduces costs of existing products. Meanwhile, patents are valuable to an inventor because they enable the inventor to limit use of the

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16. See Congressional Budget Office, *The Benefits and Risks of Federal Funding for Sematech* (September 1987).

17. In the case of tax incentives, however, there is a cost to the government -- reduced tax receipts -- for conducting the program.

patented invention.18/ Thus, at the same time that patents encourage innovative activity, they limit the use of the resulting inventions. A new product or process yields greater social benefit the more rapidly it is diffused.

On the other hand, in many cases, a patent provides only limited protection, so competing firms can frequently use the invention.19/ The characteristics of an invention can often be achieved in a variety of ways. When a patent promises to generate significant profits, others have an incentive to develop products or processes that achieve the same result in a different way--that is, they try to invent around the patent. By the same token, innovating firms try to protect their monopoly position by discovering and patenting these alternative technologies before their rivals do so.20/ R&D activities designed to invent around a patent as well as those designed to protect a patent rarely represent significant technological advances and therefore have limited social value.

Tax Policy. The Economic Recovery Tax Act of 1981 established the Incremental Research and Experimentation Tax Credit. The tax credit is available to corporations that increase their expenses for qualified research and experimentation above the average of what they had been for the previous three years. The amount of the credit was originally set to equal 25 percent of the difference between the average and the current year spending on R&D, and was reduced to 20 percent by the Tax Reform Act of 1986.

While the Congress designed the tax credit to encourage firms to expand their innovative efforts, there is some question as to how effective it has been. Some firms would have increased R&D spending

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18. There is no ban to a foreign firm using a U.S. process patent --without the consent of the holder of the patent--exporting the resulting final product to the United States. Proposed amendments to the National Cooperative Research Act of 1984 (Public Law 98-462) would provide the patent holder a right of action.

19. For a discussion of how innovations are disseminated, see S.G. Winter, "Knowledge and Competence as Strategic Assets," in David Teece, ed., *The Competitive Challenge* (Cambridge, Mass.: Ballinger, 1987), pp. 176-180.

20. For example, when it invented nylon, the first synthetic fiber, Dupont also patented a number of related products. See F.M. Scherer, *Industrial Market Structure and Economic Performance* (Chicago: Rand McNally, 1970), p.391.

regardless of the tax credit; yet, they still receive the tax credit.21/ In addition, under certain circumstances, the R&D tax credit actually provides an incentive for a firm to postpone an increase in R&D.22/ It is not surprising, therefore, that some analysts have found that the lost revenues from the tax credit exceed the resulting increase in private sector expenditures on R&D. One study, however, found that the tax credit generated two dollars in added R&D expenditures for every dollar of lost tax revenues.23/

Nevertheless, even if the tax credit encouraged additional research, it does not provide any incentives for firms to change the mix of investment projects they would otherwise undertake. Firms will still stress R&D intended to yield proprietary results. Yet, this is just the type of research that firms have ample incentives to perform. It would seem to be more desirable for the government to use its resources, whether actual outlays or tax expenditures, to encourage research that has greater social value.

Technology Transfer. The government's return on its research and development expenditures is greater when the results of the research are widely disseminated. Society benefits if a technology that the government developed for one purpose can be effectively used for another purpose. As concerns grew about U.S. competitiveness during the 1970s, the Congress began questioning whether it was receiving an adequate return from its R&D expenditures. As a result, it enacted a number of measures designed to improve the commercial use of technologies developed in government laboratories.

This problem of transferring technology is greatest with respect to government-owned laboratories. Some of these laboratories are among the finest research facilities in the country. The national labs devote much of their resources to issues, like defense, that are almost

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21. A firm with planned research and experimentation (R&E) expenditures below its three-year base would receive a greater tax subsidy from deferring a marginal R&E project than from advancing it. This advantage occurs because incremental expenditures below the three-year base would not qualify for the credit, but would count in the firm's average for future credit.

22. See, for example, Kenneth Brown, *The R&D Tax Credit* (Washington, D.C.: American Enterprise Institute, 1984).

23. See testimony of Martin Neil Bailey, Hearing before the Subcommittee on Taxation and Debt Management, Committee on Finance, U.S. Senate, April 3, 1987.

exclusively the concern of the government. Consequently, many firms in the private sector do not pay close attention to the research performed at the national labs. Nevertheless, some of the technologies developed in these facilities may have important commercial applications. With government laboratories accounting for more than a third of government-financed R&D, the gains from an increased transfer of technology are potentially very large.

In 1980, the Congress passed the Stevenson-Wydler Technology Innovation Act (Public Law 96-480). Among other things, this act required many of the more than 700 national laboratories to create offices to identify the discoveries or advances that held possible commercial applications. It also established an office in the Department of Commerce to act as an information clearinghouse for patents and to license technology developed in federally funded R&D programs. Furthermore, the Stevenson-Wydler Act required the national labs to provide technical assistance to firms in the private sector that were trying to develop commercial uses for technologies developed in the national labs.24/

The Federal Technology Transfer Act of 1986 sought to expand still further the commercial use of R&D conducted in federal laboratories. One of its more significant provisions allowed individual federal laboratories to enter into cooperative research ventures with universities and private firms. Moreover, in developing these cooperative arrangements, preference is to be given to American businesses producing domestically.

The Congress also changed the way that its patent laws apply to inventions made in connection with government-funded R&D. Before the adoption of the Patent and Trademark Amendments of 1980, the various agencies supporting R&D did not apply uniform standards for licensing the technologies that firms or universities developed while conducting government-sponsored research and development. In fact, many agencies maintained title to their patents and licensed them on a royalty-free basis to anyone expressing an interest. This policy

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24. Thus far, they have only acted in an informational capacity. For a discussion of this and other issues, see Wendy Schacht, "Stevenson-Wydler Technology Innovation Act: A Federal Effort to Promote Industrial Innovation" (Washington, D.C.: Congressional Research Service, December 1, 1986).

prevented a firm from obtaining patent protection for its new product or process, thus making firms reluctant to develop commercial applications. The Patent and Trademark Amendments developed a consistent set of standards for licensing government patents that all agencies must apply. Specifically, they assigned the ownership of patent rights to any small business and nonprofit contractors involved in federally funded projects. The government, however, reserved the right to have royalty-free use of inventions. A presidential memorandum then extended this policy to large businesses as well.

In the same vein, the Congress further changed the patent law so that government agencies could issue exclusive licenses for technologies invented in government laboratories. The licenses are granted, however, only for commercial use of inventions in areas specifically indicated by the firm. The exclusivity is intended to encourage firms to search for promising fields of technological application. Since firms often do not fully anticipate the potential uses of technologies when they are first developed, temporary title is permitted for up to four and one-half years before requiring the disclosure of the intended commercial application.

Finally, the Federal Technology Transfer Act of 1986 increased the incentives of scientists and engineers employed in government labs to recognize the commercial potential in their work. The legislation required agencies to give 15 percent of any royalties from a license to the inventor. In addition, the act directed the heads of agencies with large laboratories to institute a cash award system to research personnel who make significant advances.

Technology transfer provides important benefits. In some sense, the government's actions in this regard epitomize the four criteria of government programs that successfully encourage commercial innovative efforts. The government has taken steps to keep the private sector aware of federally sponsored research and to help firms make commercial use of these technologies. At the same time, the results of the government's research will undoubtedly spur innovative action by the private sector, and firms will bear the financial risk of any attempt to use the technologies commercially.

While the government's technology transfer programs clearly have important benefits, they have their limits as well. Much of the technology developed by and for the government responds to specific government needs. In many cases, these technologies simply do not have important commercial applications. Moreover, truly significant discoveries would, in virtually all cases, be disseminated widely even without efforts to transfer technology. Moreover, the potential for substantial compensation for commercial innovations may discourage employees from giving due diligence to the primary missions of the labs. Thus, at some point, the cost of further technology transfer will exceed any additional benefits.

CHAPTER IV

OPTIONS FOR STIMULATING COMMERCIAL INNOVATION

Many factors affect the competitiveness of a nation. Analysts have cited, for example, the skills of the work force, the quality of the management, and the level of savings and capital investment as important determinants. Despite their significance, government policies affect these areas only indirectly. On the other hand, a nation's productivity and innovativeness are also important to its competitiveness. As a major funder of the nation's research and development efforts, the federal government plays an important role in the innovative efforts of the United States.

THE PROS AND CONS OF FURTHER GOVERNMENT EFFORTS

It is natural that the Congress should consider modifying its R&D policies as a means of increasing competitiveness. In the first place, a nation's R&D efforts directly affect its innovativeness. Moreover, the government has substantial experience in developing and administering R&D programs. Finally, as discussed later, specific factors may warrant increased government support.

Yet, there is an important reason for the government to maintain a limited role. The overriding premise of a market economy is that the decisions of private firms left to their own devices lead to the best allocation of a nation's resources. Accordingly, government attempts to influence economic activity should be limited to those cases where it can be demonstrated that the market is not providing private firms with the proper incentives.

Reasons for Further Government Support of Private Sector R&D

As with any policy, the Congress should compare the expected benefits of a program designed to spur innovative activity with its costs. In addition, a number of unique factors should be considered in making such an evaluation.

Augmenting Military R&D. Although government R&D programs have rarely attempted to foster primarily commercial innovations, these programs have nevertheless generated significant commercial spillovers. Even if the objective had been to spur commercial innovation, it is doubtful that the government would have found products with larger commercial impacts than the semiconductor, computer, or jet aircraft.

For the most part, the government R&D programs that have generated the largest commercial payoffs have involved procurement. Over time, however, products developed for the government have become more specialized and less revolutionary; as a result, potential commercial applications are apparently declining. Current Department of Defense efforts to develop semiconductors that can function in a highly radioactive environment epitomize this trend. By expanding the state of knowledge, the underlying research could lead to civilian advances. Commercial applications of this research will probably not, however, in any way be comparable with the earlier semiconductor research. Similarly, the aerospace industry is developing aircraft that are difficult for radar to detect. Some analysts allege that the decline in the technological significance of the Department of Defense's R&D stems from the reduced willingness of the department to explore potential breakthrough technologies.1/

If it is indeed likely that military R&D will open up significantly fewer new technologies in the future, then an important source of commercial innovations has been curtailed. Moreover, because many of the technologies that the military was instrumental in developing involved large costs and great risks, they are precisely the type of activities that private firms are reluctant to undertake. Thus, one argument for the Congress to provide increased support for govern-

1. See W.R. Neikirk, "Commercial Benefits of 'Star Wars' Disputed," *Chicago Tribune*, December 31, 1987, p.10.

ment R&D efforts is to fill the void created by changes in the mix of products that the government procures.

Supporting Strategic R&D. A nation benefits when its firms can charge prices above costs for products that it exports. It can sometimes be beneficial to the economy if the government helps to create such "national champions."2/ These benefits may be greater when another nation is attempting to create its own national champions in the same market. In that case, a nation not only increases the likelihood that it will be able to export products at prices above their costs of manufacturing, but it reduces the likelihood that its consumers will have to import from foreign firms with market power.

Government support of R&D may help develop national champions. A product innovation faces little competition, and so its price is often high relative to its cost. Similarly, a new process lowers the innovating firm's cost of production below the prevailing market price. Innovating firms can maintain their ability to set prices above costs only if access to specialized assets or information is restricted.3/ In most cases, however, other firms eventually imitate the innovation, and prices ultimately decline to costs.

Since an innovator cannot indefinitely maintain prices above costs, the benefits to the nation of creating a national champion may be short-lived. A number of factors can extend the time in which an innovator is able to maintain a price that exceeds the cost of production.4/ Firms can sometimes maintain lower costs than their rivals by expanding rapidly and achieving efficiencies associated with large-scale production. Because they are the first to enter an industry, innovators generally have an advantage in achieving such econo-

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2. The value of a nation's exports eventually tends to be equal to the value of its imports. When the price of a good tends to equal its cost of production, which is the case with a competitive market, the value of the resources in a nation's imports and exports tend to be equal. Thus, if firms are able to set prices above costs for their exports, the nation will have more resources available to produce for its own consumption. For a discussion of these issues, see Paul Krugman, ed., *Strategic Trade Policy and the New Industrial Economics* (Cambridge, Mass.: MIT Press, 1986).

3. See David Teece, "Profiting from Technological Innovation: Implications for Integration, Collaboration, Licensing, and Public Policy," in David Teece, ed., *The Competitive Challenge* (Cambridge, Mass.: Ballinger, 1987), pp.185-219.

4. There are, however, costs to rapid expansion. See, for example, F.M. Scherer, *Industrial Market Structure and Economic Performance* (Chicago: Rand McNally, 1970), pp.77 and 78.

mies.5/ Firms can also maintain their market position by continually improving their product, and government support for R&D may be able to help in these efforts.

Helping U.S. Manufacturing. A final possible reason for supporting domestic manufacturers' innovative efforts is evidence that foreign firms are performing better than domestic firms. Recently, Japanese firms have established a reputation in a number of industries for being efficient producers of high-quality products. If such a gap in efficiency exists, increased innovativeness by domestic manufacturers may be able to close it. Moreover, between 1960 and 1985, output per man-hour in manufacturing increased at an average annual rate of 8.0 percent in Japan versus 2.7 percent in the United States.

Numerous factors account for the success of certain sectors of the Japanese economy. After World War II, the Japanese economy was decimated and, for much of the post-War period, the Japanese have used technologies developed elsewhere to catch up to the United States and other industrialized nations. Yet, their rapid growth in productivity undoubtedly reflects more than simply incorporating other technologies. For example, some analysts maintain that their success has stemmed, at least in part, from the close working relationships between Japanese firms and their suppliers. At the same time that these relations enable Japanese firms to design products that are highly reliable, they may also enable Japanese firms to design products that can be produced efficiently.6/ Finally, this apparent greater efficiency might also stem from the relatively larger share of their R&D resources that Japanese firms devote to process technologies.

Reasons for Limiting the Government's Role in Private Sector R&D

Many analysts argue that the government should interfere in the investment and operating decisions of private firms only when evidence exists that the market is producing an unacceptable outcome.

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5. Some analysts maintain that these so-called first-mover advantages are overstated. See, for example, N. Rosenberg and W.E. Steinmueller, "Why Are Americans Such Poor Imitators?" Stanford University, unpublished paper, December 21, 1987.

6. See N. Rosenberg and W.F. Steinmueller, "Why Are Americans Such Poor Imitators?"

Such market failures usually take place when the price that a firm must pay for a resource does not reflect its true social value. Thus, the inability of a firm to appropriate fully the economic rewards of its innovations represents a type of market failure. There is little evidence, however, that this kind of market failure is hindering the competitiveness of domestic manufacturers. The use of further government support for R&D to create commercial private sector innovations may, therefore, not be advisable.

The government simply does not have the expertise to choose among competing technologies. Moreover, since the government does not respond well to market signals, it would have a tendency to continue substantial support for projects that offer limited commercial potential. Furthermore, the nation's supply of resources used for research and development cannot be instantly increased. Consequently, a decision by the government to increase research in one area may lead to reduced research efforts in other areas.

Moreover, some evidence indicates that the private sector is responding to the changing competitive situation. Private sector expenditures on R&D have increased substantially since the mid-1970s. In addition, a number of companies have made extensive efforts to restructure their operations in order to increase productivity.

This argument is, nevertheless, consistent with the government having a critical role in supporting the nation's research and development efforts. As considered previously, the private sector has a tendency to underinvest in R&D, especially in areas like basic research, where any commercial benefits are unknowable and any payoffs will not be realized for an extended period of time. It is therefore in the nation's interest for the government to sponsor such research. As part of these efforts, however, it would be beneficial for the government to make the results of the research available to the private sector and to encourage the scientists and engineers performing the research to interact with the private sector.

If, in fact, foreign firms are becoming more innovative and more efficient relative to domestic firms, the reason may have nothing to do with technology. Instead, the decline in competitiveness may reflect, for example, the levels of capital investment. It might also reflect the quality of the nation's management and its work force. Domestic plants operated by Japanese management have proven to be quite efficient with the same machinery as plants operated by domestic manufacturers. If the apparent decline in competitiveness is not the result of a lack of innovativeness, increasing government support for R&D may do more harm than good. Further government efforts may encourage some domestic firms to delay taking the steps necessary to improve their ability to compete in international markets. Government actions to improve competitiveness might be more effectively aimed at promoting stable economic growth and increasing the quality of education.

The problems of new technologies being appropriated is roughly the same for countries as it is for firms. Thus, even if the Congress managed to increase innovativeness among domestic firms, these new technologies could quickly be adopted in other countries. In fact, a U.S. firm might conceivably decide to manufacture a new product in a foreign country. Even if the domestic firm received substantial benefits from such an innovation, the gains to the U.S. economy could, nevertheless, be relatively small. Similarly, foreign firms may be able to copy a new technology. In other words, the advantage to the domestic manufacturer of stimulating a particular innovation might be short-lived.

WAYS THAT THE GOVERNMENT CAN ASSIST COMMERCIAL R&D

If the Congress decides to take additional steps to increase the innovativeness of the private sector, any program it introduces should be consistent with the four criteria mentioned in the previous chapter. Specifically, the private sector should be aware of government-sponsored research; good communication should exist between those doing the relevant research and those developing the product; firms should retain full commercial and financial responsibility for introducing an innovation; and finally, government efforts should stimulate R&D by firms. In addition, when it explicitly tries to aid commercial innovative efforts, the views of the private sector should influence the direction of the research that is funded.

A broad array of programs would meet these objectives. They range from general policies that affect a broad spectrum of industries to policies seeking to aid a particular industry. Moreover, efforts to increase commercial innovations may simply expand existing efforts, like technology transfer, or they might represent entirely new endeavors. Five options are discussed below.

If the Congress chooses to adopt a policy to stimulate commercial innovation, it should be mindful of why it is doing it. A program is most likely to be effective if it is designed to meet specific goals. In addition, any policy will be more beneficial if it is tailored to meet the perceived shortcomings of current R&D initiatives in the private sector. For example, the preceding analysis suggests that firms place too much emphasis on development and product innovations in performing their R&D.

Increase Efforts to Transfer Technology

In the 1970s, with concerns about the competitiveness of domestic manufacturers growing, some analysts questioned whether the private sector was adequately using government-sponsored research. Since then, the Congress has adopted a number of measures to facilitate such transfers of technology. While these efforts have undoubtedly had a positive effect, it has nevertheless been small. Apparently, government laboratories do not hold scores of inventions that can be readily commercialized, although in a number of cases technology transfer did make research results available to firms sooner.

The primary benefit of technology transfer has been to increase cooperation between researchers in the national labs and the private sector. Such interactions have stimulated the innovative activities of the private sector at a modest cost. Encouraging further technology transfer by increasing personnel exchanges between the national labs and private firms may also pay dividends.7/

Successful research often entails seeing an entire class of problems from a new and different perspective. A scientist can rarely

7. Similarly, scientists in universities working on government-supported contracts may not fully appreciate the applicability of their research.

convey such insights adequately in an academic paper or through a presentation at a conference. In some cases, the scientist performing the research may not fully appreciate the implications of the discovery. More extensive use of the research results of the national labs might require the scientists and engineers making the discovery to work more closely with those trying to apply and extend the results. As part of its efforts to transfer technology to the private sector, the Congress might consider taking steps to encourage further interaction between researchers of the national labs and scientists and engineers in the private sector.

By his Executive Order of April 10, 1987, President Reagan gave further impetus for national labs to create such exchanges. While a number of such programs already exist, for the most part they involve private sector researchers visiting government-owned facilities. It might be equally valuable, however, for government researchers to visit private laboratories. Numerous institutional hurdles have been crossed to establish these programs, and further hurdles will probably have to be crossed to expand them. Questions have had to be answered about the types of research that visiting scientists will perform as well as the rights to any resulting discoveries. Moreover, firms may fear that visiting government researchers would be exposed to proprietary research. Yet, increased interaction may encourage private firms to take better advantage of the research in the national labs.

Privatize the National Labs

A number of the national laboratories rank among the world's finest research facilities, and in many respects they resemble universities. But while scientists at universities perform research for a variety of clients, those at the national labs work almost exclusively for the government. Private sector use of the national laboratories is largely limited to the use of specialized facilities, such as particle accelerators.

The Congress has taken a number of steps to increase the sensitivity of scientists in the national labs to the commercial possibilities of their research. These initiatives recognize that society receives the largest return on its investment in R&D when scientists are able to use their discoveries broadly. In the case of the national labs, such multiple uses may be best achieved if the laboratories worked on projects sponsored by the private sector as well as those sponsored by the government.

The Congress has given the managers and the employees of the national labs incentives to perform research with commercial applications. Yet, since they are government-owned facilities, commercial research will invariably remain of secondary importance. If a national lab were privatized, however, it could perform research for the government as well as the private sector, and the know-how of the national labs would be more likely to be used broadly. Moreover, if there were significant private demand for services at the national labs, privatization could lead to their improved use and thereby make them more efficient.

More specifically, the national labs could become private--and perhaps nonprofit--research facilities that operate independently of the government. Under such an arrangement, both the government and the private sector would be able to contract with the labs to do the research. Consequently, the labs might have greater incentives to find commercial uses for new technologies. By the same token, the government would have greater flexibility in choosing who would do needed research.

If privatization gave a national lab operating flexibility, it could use its resources more creatively. For example, giving employees of the labs the latitude to develop working relationships with firms might encourage high-technology firms to establish facilities nearby. Such proximity promises to encourage the use of technologies--like those that are the outcome of government-supported basic research--discovered at the lab. In fact, some of the Department of Energy's multiprogram labs, which are operated by contractors, have already taken steps to encourage the growth of nearby private firms.

Privatization could, of course, impose substantial costs. The national labs currently receive their entire operating budgets from one highly dependable source--the federal government. While the government would still be a major consumer of their services, a private lab might have to spend a significant share of its resources marketing its services both to the private sector and to the government. In that case, privatization would reduce the resources the labs had available for research. Moreover, the press to develop business in the private sector may interfere with the ongoing research of the labs. It is difficult, however, to gauge the size of private sector demand for the services the national labs can provide. If demand proves to be small, privatization could produce substantial costs with little gain.

Although over 700 national laboratories exist, only a handful could be considered candidates for privatization. These would include labs with an array of resources that the private sector would have an interest in using. Less diversified facilities may experience substantial difficulty in generating interest from a cross-section of firms. The Department of Energy multiprogram labs that do not concentrate on defense research would be logical candidates.8/ They have expertise in a variety of areas--most notably materials research--that may be quite relevant to the needs of the private sector.

Research financed by the National Institutes of Health has played a major role in the pharmaceutical industry and has helped to spawn the field of biotechnology.9/ Privatizing NIH may, therefore, also have considerable benefits. Moreover, privatization would give NIH more flexibility in compensating employees. Because they are operated by contractors, the Department of Energy's labs are not restricted by civil service regulations in compensating their staffs.

Make Commercial Considerations an Integral Part of Procurement Decisions

Of all the ways in which the government has supported R&D, developing products that it ultimately purchases has produced the greatest commercial impact. When the government supports the development of a product it ultimately procures, it helps endow the firm with substantial knowledge and expertise. If the technology can be used commercially, the firms that developed it are uniquely positioned to apply it.

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8. All the labs perform some defense work. As part of any move to privatization, ongoing research for some projects involving classified matters might have to be transferred to other laboratories.

9. See, for example, "Budget Plan Would Privatize National Institutes of Health," *The New York Times*, December 16, 1987, p. 1. For criticism of the proposal by a former researcher at NIH, see Philip Leder, "Privatizing NIH is an 'Idiotic Idea'," *The New York Times*, January 12, 1988, p. A27.

The potential for commercial spinoffs has never been an important factor in determining the products the government procures. One possible way of increasing competitiveness is to make commercial considerations an integral part of the procurement decision. For example, the Department of Defense might fund the more costly of two alternative development strategies, if it held a greater prospect of generating commercial spinoffs. In addition, DoD could purchase more of its needs from products that were already commercially available. Such a policy might reduce acquisition costs and reduce R&D spending by the military. At the same time, it might also encourage greater commercial innovative efforts by the private sector. The government is a major purchaser of a huge array of civilian products. It might, therefore, be possible for the government to help develop and then procure products that have far-reaching commercial applications. These might include new types of computers, solar photovoltaic cells, or some entirely new class of products.

A number of potential roadblocks threaten the effective use of procurement to promote civilian innovations. DoD, which has funded the bulk of R&D associated with procurement, has the personnel capable of evaluating recent technological developments. Nevertheless, it has little experience in evaluating commercial markets. The situation would be vastly different with civilian procurement--no civilian agency keeps abreast of technological developments that might affect the products the government would purchase in the future. Consequently, if the government uses civilian procurement to increase competitiveness, there is a distinct possibility that it will develop products with limited commercial potential or it will support research that the private sector would have funded in any case.

Encourage Jointly Funded Research Projects

Interest has been increasing in R&D efforts that are jointly funded by the government and industry. In addition to the Engineering Research Centers, the Reagan Administration has proposed that Science and Technology Research Centers be established. These would operate similarly to the Engineering Research Centers, but cover different areas. Moreover, as mentioned earlier, the Congress has recently decided to fund, jointly with a number of firms, Sematech--a research effort to find more efficient ways of manufacturing semiconductors.10/

Since most of these jointly funded research projects are relatively new, they cannot yet be evaluated. Nevertheless, they seem to be a logical way to boost commercial innovativeness. First, because private firms are, at least in part, funding the research, they clearly have some expectation that the results will be useful. Moreover, because they have a financial stake, firms have a substantial interest in both influencing the direction of the research as well as monitoring the results. Also, in a consortium the research tends to be generic and thus has only limited overlap with the research that firms would otherwise perform.11/ Finally, such programs are one of the few ways that the government can encourage firms to devote greater efforts toward making process innovations.

A further advantage of a joint funding approach is that it can provide the government with a basis for determining whom to support. The government could ask interested parties to form consortia and each consortia to submit a request for government funding of research or the establishment of a research center.12/ These requests could describe the goals of the research, the participants, and the requested contribution of the government. The government could then judge the relative worth of the various programs and determine which of the proposals to fund. Meanwhile, competition among the consortia for funds should limit government expenditures.

A goal of this program would be to encourage innovative activity. If the firms would have established a cooperative research effort without the government, then government support would contribute nothing. In fact, the National Cooperative Research Act of 1984 encouraged such private efforts by modifying the antitrust laws. Never-

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10. See Congressional Budget Office, *The Benefits and Risks of Federal Funding for Sematech* (September 1987).

11. If the research is not generic but relates to future product designs, then the consortium may limit competition in the design of new products. Consortia devoted to process innovations may also be socially harmful if they limit, rather than encourage, firms' efforts to find low-cost production techniques. This might happen if the consortium and hence the member firms limit their efforts to only one technology.

12. In funding the Engineering Research Centers, the National Science Foundation essentially asked universities to serve as matchmakers in the formation of the research consortia.

theless, the prospect of government funding would clearly encourage the formation of additional cooperative efforts. Under such a program, the government should try to avoid funding proposals that it has reason to believe would operate without government support. Unfortunately, this is not easily determined.

Government support may be critical in forming such cooperative ventures. The parties bring a range of skills and knowledge to a joint research project--some of which are more valuable to the project than others. In considering whether to join a consortium, a firm must consider its expected gains as well as those of its existing or potential competitors. Thus, a firm would be reluctant to join if it perceives that other firms would benefit from its research, while it would receive little in return. By providing additional resources, government support may increase the likelihood that the consortium will produce significant results. Consequently, it may increase the willingness of the most technologically advanced firms to join.

Foster New Industries

Some government-supported R&D efforts have helped to launch entirely new industries. When the Department of Defense saw the potential uses of products like the semiconductor and the computer, it provided funds to speed their development. These advances not only provided important new uses for the military, they spawned a wide range of civilian products as well. In addition, government support propelled U.S. firms into world leadership in these rapidly growing industries.

Several nonmilitary efforts have yielded technological breakthroughs that have essentially spawned new industries. Perhaps the most significant is the emerging field of biotechnology. Basic research sponsored by NIH has been instrumental in developing this industry. Because of its unique mission, NIH was in a position to provide substantial support, even when scientists could scarcely appreciate the commercial potential of their work.

In these cases, the government did not support the research because of its potential commercial applications. The Congress might therefore develop programs that have a primary objective of developing new and potentially vibrant industries. Ironically, the few cases in which the government explicitly sought to develop new technologies for commercial purposes have largely been failures. Despite large expenditures for both synthetic fuels and the breeder reactor, government support did not yield viable commercial outcomes.

If the Congress should try to foster new industries with its support of research, it should keep in mind the lessons of its past efforts. In the case of the successful efforts, the private sector, including researchers in colleges and universities, played an important role in the innovative process. Moreover, the technological advances in these projects were iterative--the results of past R&D dictated the pace and the direction of future research. On the other hand, when the government attempted to develop a commercially viable method of manufacturing synthetic fuels, the objectives largely directed the research. While such objective-driven research might be desirable in developing products for government procurement, it usually is not appropriate for creating commercial products or processes. Even if the R&D is successful in creating new technologies, these technologies may not yield profitable processes or products.

In the other options discussed in this chapter, firms have a central role in the innovative process. Such a role is not necessarily the case with this option. Therefore, in designing programs to create new industries, the government should keep in mind the four criteria previously discussed.

WHO WOULD CHOOSE?

With a few minor exceptions, government efforts to encourage innovation by the private sector have not been directed at specific industries. Currently, no government agency monitors both technological and competitive developments in the economy. Moreover, in areas that are related to neither health nor energy and do not have military applications, often no agency stands ready to sponsor promising applied research. Yet, some of the options discussed above would require someone in the government to make decisions not only about the viability of various technologies, but also about future trends in the marketplace. Thus, if the Congress decides to introduce such policies, it must also decide who would administer them.

In selecting industries for government assistance, a number of factors must be considered.13/ For example, it is essential that a fertile technological base underlie the industry's products--that is, there must be ample opportunities in the industry for innovation. Since the rate of innovation is determined by demand as well as supply, the prospect of rapid future growth for the industry may also be desirable.14/ Furthermore, the greater the potential spillovers from the innovations, the greater the benefits from aiding the industry. Helping an industry that produces technology for a variety of industries--such as machine tools or semiconductors--may provide greater benefit to the economy than helping an industry that produces predominantly consumer products.

At present, no agency combines the ability to analyze both the technological and economic aspects of the nation's manufacturing sector. Even if the Congress does not try to stimulate innovations in particular industries, it may want to either establish such an agency or expand the responsibilities of existing agencies. With the growth of trade and competition in the world economy, the Congress, the Executive Branch, and the private sector might benefit from an agency with such expertise.

A number of existing agencies already have significant technological expertise and could be expanded to provide the economic analysis that would be required:

- The *National Science Foundation* is a principal supporter of the nation's basic research efforts. With the establishment of the Engineering Research Centers, it has also become active in promoting applied research. Moreover, NSF monitors the funding and performance of R&D in the economy.

13. For a discussion of the arguments for and against providing support for a particular industry, see Congressional Budget Office, *The Benefits and Risks of Federal Funding for Sematech*, pp. 27-37.

14. The government might also be concerned with whether the attributes of the product make it probable that domestic firms will manufacture the product in the long run. See, for example, David Teece, "Profiting from Technological Innovation: Implications for Integration, Collaboration, Licensing, and Public Policy," in David Teece, ed., *The Competitive Challenge.*

- The *National Bureau of Standards* aids industry by developing standards and measurement techniques. As part of these functions, it monitors technologies being developed in the economy and works closely with scientists and engineers in the private sector.

- The *Department of Defense* has been far and away the largest supporter of research and development in the government. Moreover, it has overseen the development of a number of new technologies that have had far-reaching commercial effects.

In each of these cases, however, the added responsibilities are not completely consistent with the existing missions of these agencies. As a result, there is a risk that the existing programs might suffer or that the new duties will not be adequately carried out. For example, it would be a significant loss to the nation's science base if NSF support of basic research at colleges and universities were to decline. While DoD clearly has extensive experience in developing new weapons systems, it has virtually none in developing products for commercial markets. Moreover, such an effort would be totally inconsistent with its mission. These added duties would probably be most consistent with the current mandate of NBS. NBS, however, is a comparatively small agency,and these new responsibilities would represent a substantial expansion of its mission.

An alternative approach might be to expand an agency with economic expertise. Most notably, the Department of Commerce maintains a staff of economists and analysts to monitor trends in the industry. Moreover, NBS is part of the Department of Commerce. Administering such an R&D program, however, would represent a radical departure from the Department of Commerce's existing responsibilities so that its economic expertise may be of limited usefulness.

While some of these agencies may be more appropriate for handling these additional functions than others, none currently has the relevant expertise. Thus, if the Congress decides that the government should have an agency to oversee technological and economic developments, it has two choices. First, it could substantially expand the duties of an existing agency. Alternatively, it could create a new agency. This new agency could also include some or all of the functions of the agencies that currently support the nation's research and development efforts.

APPENDIX

THE EFFECT OF INNOVATIVENESS ON THE RELATIVE PERFORMANCE OF INDUSTRIES

After World War II, the United States accounted for over 60 percent of the world's manufacturing output. Unlike many of its trading partners, domestic firms were not only unscathed by the war, but they expanded considerably during it. At first, Europe's and especially Japan's lower labor costs were critical to the growth of their manufacturing exports after the war. As they expanded, however, European and Japanese producers made ample use of the expertise and the technologies developed in the United States.

Since European and Japanese manufacturers increasingly used the same production techniques as domestic producers, the advantage in productivity of U.S. manufacturers slowly eroded. More recently, newly industrialized countries such as Taiwan and South Korea were also able to employ roughly equivalent technologies in many basic industries such as textiles and steel. In fact, by establishing foreign subsidiaries and exporting the requisite capital equipment, the United States and other developed countries fostered the transfer of these advanced technologies.

Developing countries have become important producers of a number of products--like color televisions and semiconductors--that once were considered "high tech." Yet, firms in developed countries still introduce most of the technologically sophisticated products. New products frequently incorporate new scientific developments, so introducing them generally requires a core of highly skilled and technologically sophisticated workers. Such employees are relatively more abundant in the work forces of developed nations.

But the production of all products does not inevitably gravitate toward less developed countries. In the first place, some products change constantly. Firms generally need a sophisticated work force to produce a technologically sophisticated product that continually changes. This factor is perhaps most clearly illustrated in markets for customized integrated circuits. Since the chips are designed and built to serve a particular need, no particular design ever achieves sufficient sales to permit substantial specialization in production.

Firms in developed countries, however, can remain significant producers for some standardized products that are produced in high volume. One way a firm can achieve such an outcome is to adopt new production processes continually. Since these new processes are generally more capital intensive, labor becomes a smaller part of the cost of the product. When a production process becomes sufficiently capital intensive, the significance of the lower wage rates in developing countries is reduced. Of course, other factors--such as management, quality control, and logistics--may encourage firms to keep their production in industrialized nations.

Nevertheless, firms in developed countries can generally compete most effectively in markets for high-technology products. Trade flows in recent years certainly support the contention that this is true for the United States. While the economic developments of the 1980s adversely affected almost every domestic industry, those that could be classified as high technology did relatively well.

Classifying industries based on their technological progressivity is somewhat arbitrary. The Congressional Budget Office (CBO) considered industries to be either high-, medium-, or low-technology based on expenditures on research and development as a percentage of sales, as reported by the National Science Foundation.1/ Yet, such a measure can either overstate or understate the technological progressivity of an industry. For example, industries that purchase a lot of high-technology components and thus make what could be considered state-of-the-art products would not necessarily be classified as high technology. Likewise, the measure can also overstate the technological progressivity of some industries. Development includes activities

1. The Congressional Budget Office used National Science Foundation data to classify industries by how intensively they performed research and development. NSF collects annual data on industry expenditures of research and development and publishes those expenditures as a percentage of sales. Much of the data are at the two-digit SIC level, although some two-digit industries, such as textiles (SIC 22) and apparel (SIC 23), are combined, and there are some three-digit industries. Using this NSF data, CBO divided manufacturing into 21 separate industries and classified industries as high-, medium-, or low-technology based on their reported research and development expenditures as a percentage of sales. NSF did not publish some data to preserve confidentiality, so CBO estimated these data. Data on exports, imports, shipments, employment, and capital expenditures came from the Department of Commerce.

such as style changes so that R&D intensity may overstate the technological progressivity of industries that devote substantial resources to such endeavors.

Of the three groups, only high-technology industries recorded trade surpluses throughout the 1980s (see Figure A-1). In fact, since the late 1970s, only the high-technology industries produced more in 1985 than they did in the late 1970s. Moreover, high-technology industries were alone in registering employment growth in recent years. Yet, in 1985, the high-technology industries account for only 16 percent of domestic manufacturing shipments and 18 percent of domestic manufacturing employment.

While the trade surplus of the high-technology sector grew during the 1970s, the surplus in 1986 was only one-third of what it had been in 1980. While the value of exports of these industries grew at an average annual rate of 5 percent during this period, the value of imports grew by nearly 18 percent per year.

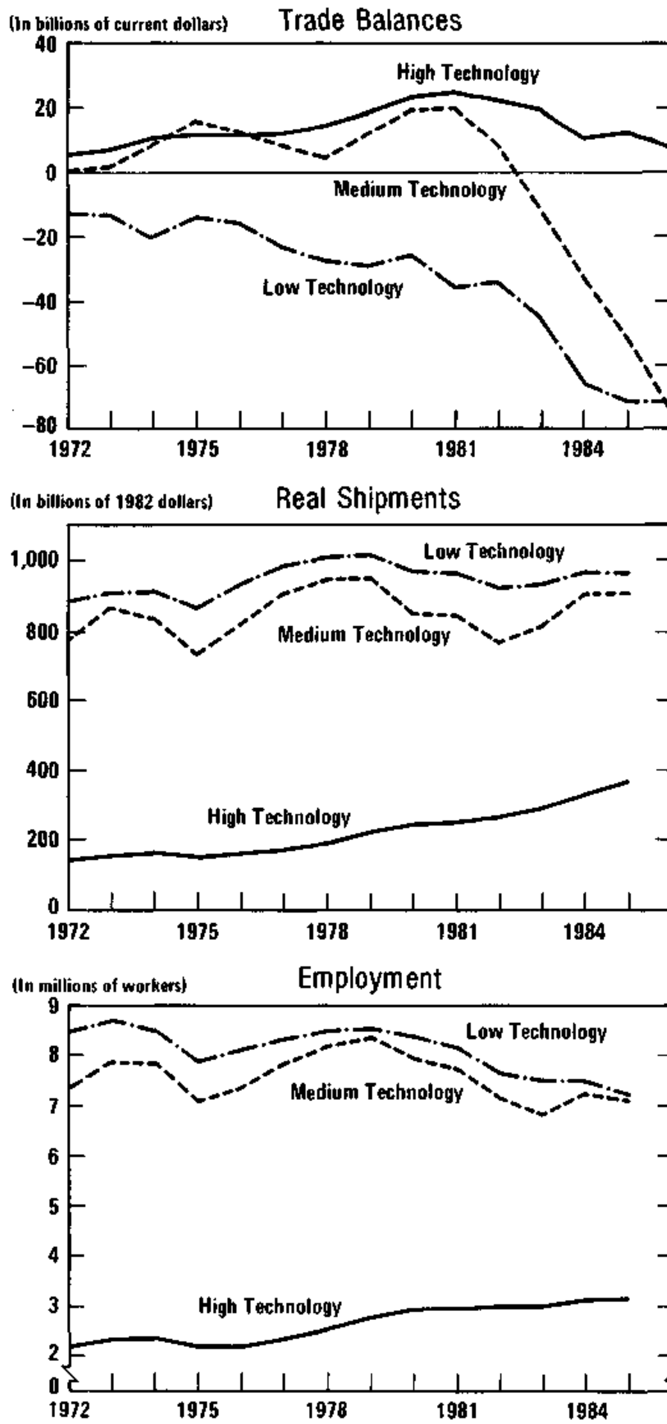
Trade balances in low- and especially medium-technology industries deteriorated much more rapidly. The trade surplus in medium-technology industries went from a surplus of $20 billion in 1981 to a deficit of $90 billion in 1986. The value of imports increased at an average annual rate of 16 percent, while the value of exports declined by 2.6 percent per year.

The trade deficit for low-technology industries doubled between 1981 and 1986. This decline, however, represented a moderate acceleration of a trend that existed throughout the 1970s. In fact, the 8 percent annual growth rate of imports was the slowest of the three groups. Exports fell at an average annual rate of 2.1 percent.

Within each group, there was a great divergence among industries. For example, growing foreign competition had a substantial effect on at least one high-technology industry--semiconductor manufacturers.2/ Analysts estimate that Japanese producers currently con-

2. See, for example, Congressional Budget Office, *The Benefits and Risks of Federal Funding for Sematech* (September 1987).

Figure A-1.
Trade Balances, Real Shipments, and Employment by Technology Level



SOURCE: Congressional Budget Office based on Department of Commerce data.

trol more than 50 percent of the world sales of dynamic random access memory chips. These devices are widely used in computers and home appliances, and for much of the 1970s they were critical to the growth of the domestic industry. Moreover, increasing imports of motor vehicles and machinery accounted for over half of the declining trade balance of the medium-technology industries. Nevertheless, of the 21 manufacturing industry groupings that CBO considered, only petroleum and aerospace improved their trade balances between 1981 and 1986 (see Table A-1 on page 82).

TABLE A-1. BALANCE OF TRADE AND GROWTH RATE BY INDUSTRY

Industry	R&D as a Percent of Sales 1980	Balance of Trade (In millions of dollars) 1980	1986	Average Annual Growth Rate of Real Shipments 1972-1980	1980-1985
Low Technology					
Food and Kindred Products	0.4	1,725.2	-1,037.65	1.65	1.69
Textiles and Apparel	0.4	-4,485.8	-19,537.20	0.55	0.39
Wood Products and Furniture	0.8	-584.4	-5,864.73	0.27	1.55
Petroleum	0.6	-10,571	-8,752.22	2.00	-0.96
Primary Metals	0.7	-6,935.8	-14,178.90	-0.42	-5.56
Other Transport Equipment	0.6	-843.1	-4,373.57	2.26	-3.95
Other Manufacturing	0.4	-3,804.9	-17,376.40	0.90	1.64
Total		-25,499.8	-71,120.60	0.14	-0.17
Medium Technology					
Paper and Allied Products	1.0	-761.8	-3,712.98	2.08	1.72
Chemicals and Allied Products	3.6	13,041.3	8,438.95	2.03	0.72
Rubber Products	2.2	-68.00	-2,446.87	1.08	5.72
Stone, Clay, and Glass Products	1.4	-340.2	-3,207.68	0.09	-0.57
Fabricated Metal Products	1.4	2,380.8	-3,095.10	0.81	0.01
Machinery, Nonelectrical	5.0	18,838.5	-1,199.64	2.48	-3.97
Electrical Equipment	4.8	-143.6	-15,051.60	2.05	1.71
Motor Vehicles	4.9	-13,110	-53,523.60	-1.38	6.90
Total		19,837	-73,798.50	1.17	1.23
High Technology					
Drugs and Medicines	6.2	1,062.3	782.36	5.06	1.78
Office and Computing Machines	12.0	5,985.1	2,178.01	25.38	30.01
Communication Equipment	9.1	215.8	-1,911.98	6.98	7.39
Electronic Components	7.9	871.0	-4,871.68	10.66	5.06
Aircraft and Missiles	13.7	12,541.3	13,093.11	4.32	2.85
Professional and Scientific Instruments	7.5	2,993.6	-1,144.42	6.43	2.87
Total		23,669.1	8,125.40	7.29	8.48
Total, All Manufacturing		18,006.3	-136,793.00	1.71	1.59

SOURCE: Congressional Budget Office using data from the National Science Foundation and the Department of Commerce.