Chapter 4
Research and Development: Financial Resources and Institutional Linkages

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HIGHLIGHTS

National Trends in Research and Development Expenditures

- **Growth in research and development (R&D) funding in the United States in the 1990s has not kept pace with inflation.** Although R&D investment was expected to have reached an all-time high of $171 billion in 1995, this amount actually represents a 2-percent real decline in R&D spending over the level recorded for 1990. Neither of the two major sources of R&D support—industry (which supplies roughly 60 percent of the total) or the Federal Government (which supplies 36 percent)—outdistanced inflation. Industry funding was generally flat between 1991 and 1995, and Federal funding has been falling annually (in real terms) since 1987.

- **Of the three major R&D performing sectors—industry, the Federal Government, and academia—the last is the only one to have registered a real increase in R&D performance during the 1990s.** The annual rate of increase in academic R&D performance, however, has been falling fairly steadily since the late 1980s. The Federal Government, which supplies about three-fifths of all funds used to perform R&D on college and university campuses, has been increasing its support of academic research continuously since 1982, even after adjustment for inflation.

International Comparisons

- **The United States accounts for roughly 44 percent of the industrial world's R&D investment total, easily leading all other countries in terms of such support.** Although the United States spent 12 percent more on total R&D in 1993 than did Japan, Germany, France, and the United Kingdom combined, these four countries collectively spent 8 percent more on nondefense R&D than did the United States.

- **The dual effects of economic recession and general government budgetary restraint have resulted in a worldwide pattern of constrained R&D funding since the late 1980s.** Total R&D expenditures have stagnated or declined in each of the seven largest R&D performing countries, and R&D-to-GDP ratios similarly have dipped in the United States (from 2.8 percent to 2.4 percent), Japan (from 2.9 percent to 2.7 percent), and Germany (from 2.9 percent to 2.5 percent). Russia has slashed its post-Soviet R&D activities.

Defense-Related Issues

- **The lack of real growth in industrial R&D performance in the 1990s is largely due to the defense drawdown.** Federal funding of R&D performed by companies has been falling steadily in both current and constant dollars since the late 1980s. The impact of defense downsizing on federally funded R&D performed by industry was particularly severe in states such as California and Texas that are heavily dependent on the defense industry. Federal R&D support to firms that perform R&D in those states dropped dramatically between 1989 and 1993.

- **The defense drawdown has had a multifold impact on federally funded R&D activity.** Not only has it engendered restructuring of some industrial and nonprofit defense contractors, but also it has triggered an ongoing dialogue over the future mission of Federal laboratories. The role of these facilities in supporting commercially relevant R&D has been expanding. For example, the annual number of new Cooperative Research and Development Agreements increased between 1987 and 1994. DOD funding priorities have also been affected as evidenced by an increase in financial support for dual-use technologies (technologies with both military and civilian applications).

Industrial Research and Development Patterns

- **The most striking recent trend in industrial R&D performance has been the increase in the proportion of total R&D performed by companies classified in nonmanufacturing industries.** Prior to 1983, nonmanufacturing industries accounted for less than 5 percent of the industry total. That share grew steadily during the ensuing decade so that in 1993, nonmanufacturing firms represented more than 25 percent of all industrial R&D performed in the United States.

- **Between 1984 and 1994, there were some significant changes among the 100 largest publicly held R&D-performing companies, although the four leading firms were the same in both 1984 and 1994.** During the decade, the number of pharmaceutical and computer hardware and software companies among the largest R&D performers rose. In contrast, the number of large defense contractors and chemical and petroleum companies among the largest R&D performers fell.

- **The ratio of company R&D funds to net sales for all R&D-performing manufacturing companies has been fairly stable since the late 1980s, despite a lack of growth in manufacturing companies' R&D financing.** In 1993, this ratio stood at 3.1 percent, similar to that recorded for other recent years. The general stability of the R&D/sales ratio in the 1990s indicates that little change has occurred in the level of importance accorded R&D, relative to other discretionary spending. That is, roughly the same proportion of companies' income has been devoted to R&D for almost 10 years. At 12.1 percent, the pharmaceutical industry had the highest and only double-digit ratio in 1993.

- **Considerable indirect Federal R&D support is provided to industry.** Between 1981 and 1994, an estimated $24 billion was provided to industry through tax credits on incremental research and experimentation expenditures, an amount equivalent to about 3 percent of direct Federal R&D support during this period. Most of the credits have been claimed by manufacturing firms, but the nonmanufacturing share has risen from less than 20 percent to about 24 percent of the total.

- **The annual number of new joint research ventures has been growing fairly steadily for nearly a decade; more than 450 of these efforts were registered under the National Cooperative Research Act between 1985 and 1994.** Most of the research conducted by these joint ventures has been process-oriented. Telecommunications and environmental research appear to be the most predominant focus areas for joint research ventures.

Government Focus by National Objective

- **Major factors influencing Federal support for R&D funding are efforts to reduce the budget deficit and the defense drawdown.** The Department of Defense (DOD) and the Department of Energy, two of the four largest sources of Federal R&D support each, had constant-dollar reductions in R&D obligations during the 1990s. In FY 1995, DOD accounted for roughly half of all Federal R&D obligations, down from nearly two-thirds of the total in 1986 at the height of the Reagan defense buildup.

- **At the same time military-related R&D spending was being curtailed, Federal investment in selected civilian R&D activities increased, including support for research aimed at improving health and the environment and for technology advancement.** The Department of Health and Human Services, which is a distant second to DOD in terms of total R&D support, had the largest absolute increase—$3.0 billion—in Federal R&D obligations during the 1990s. The proportion of all U.S. R&D devoted to health-related projects has been increasing continuously for nearly a decade. The Commerce Department registered the largest percentage increase in Federal R&D obligations during the 1990s. Nearly all of this gain is attributable to rapid expansion of the National Institute of Standards and Technology's Advanced Technology Program, a program likely to be cut back or eliminated in the near future.

Geographic Distribution of Research and Development Spending

- **Most R&D is undertaken in relatively few states.** One-half of the Nation's 1993 R&D total was expended in six states—California, New York, Michigan, Massachusetts, New Jersey, and Pennsylvania. Ten states account for two-thirds of the national total.

- **Cooperative R&D is becoming an increasingly important tool in the development and leveraging of science and technology resources.** In fiscal year (FY) 1994, Federal agencies spent approximately $2.7 billion on cooperative technology programs. Also, most states boosted their spending on these activities; in 1994, states spent a total of $385 million on cooperative technology programs, or 22 percent more than in the previous year. Thirteen states budgeted more than $10 million each for cooperative technology programs in 1994; North Carolina budgeted the most money.

0 Internationalization of Research and Development and Technology

- **Industry's use of international research/technology partnerships increased in the early 1990s.** Although the growth rate in the total number of known international multifirm R&D alliances may have tapered off since the late 1980s, such partnerships are still expanding in several high technology areas. Notably, growth is occurring in alliances involving information technologies.

- **Substantial R&D investments are being made by U.S. companies overseas.** From 1985 to 1993, the overseas R&D investment of U.S. firms increased three times faster than did the R&D performed domestically; overseas investment accounts for an amount equivalent to more than 10 percent of industry's domestic R&D spending compared with a 6-percent share in 1985. (For nonmanufacturing industries, overseas R&D represented an amount equivalent to 7 percent of their 1993 performance total, compared with a 0.4-percent share in 1985.) Most of the U.S. R&D performed abroad is undertaken in Germany and the United Kingdom, but there has been considerable growth of U.S. R&D performed in Asian countries, including Japan, Singapore, and Indonesia.

- **Substantial R&D investments are being made by foreign firms in the United States.** In 1993, foreign companies accounted for an amount equivalent to 15 percent (majority-owned foreign affiliates for 12 percent) of all industrial R&D funding in the United States, compared with a 9-percent share in 1985. Foreign-funded research was concentrated in the chemicals, pharmaceuticals, and electrical equipment industries in 1993; the majority of funding came from Swiss, German, British, Canadian, and Japanese firms. Moreover, there were about 635 foreign-owned freestanding R&D facilities in the United States in 1994; roughly one-third of these facilities are owned by Japanese companies.

Introduction

Chapter Background

Readers of this publication would be hard pressed to discover disagreement with the belief that investment in research and development (R&D) is good for the economy and the health and welfare of society. This axiom has always been the cornerstone of U.S. science and technology (S&T) policy. There is widespread consensus that the invention of new and improved products, processes, and services provides innumerable societal benefits, including a competitive and productive economy, a strong national defense, new diagnostic tools and treatments for disease, and protection of the environment. (See chapter 8, Economic and Social Significance of Scientific Research.)

Because S&T have such a pervasive impact on the quality of life and the standard of living in the United States and other industrialized nations, changes in the U.S. R&D enterprise attract considerable attention. In the past few years, a number of new trends have emerged, including an increase in domestic and international collaborative efforts within and across economic sectors, growth in R&D performed in the service sector, and industrial firms' diminishing reliance on central research facilities for new S&T breakthroughs. In addition, defense downsizing, which began in the late 1980s with the end of the Cold War, is continuing to force a reconfiguration of industrial R&D activity and a redefinition of the mission of Federal laboratories.

The change in the U.S. R&D enterprise causing the most consternation in the mid-1990s, however, is a lack of real growth in R&D investment. Although cutbacks in defense appropriations are responsible for a sizable portion of the reduction in R&D effort, the flow of dollars into civilian R&D projects also has been constricted.

The immediate outlook for U.S. progress in S&T, therefore, may not appear as optimistic as it did in the past. Despite the lack of growth in R&D funding, there are some positive signs, including

- A mushrooming of collaborative R&D efforts within and across sectors and with international partners,
- Continuing strong support for research performed on university and college campuses,
- An upsurge in state spending for cooperative technology programs, and
- Historically high R&D funds-to-net-sales ratios for all R&D-performing manufacturing firms.

The purpose of this chapter is to track these and other trends in financial investment in science and technology.

Chapter Organization

This chapter contains seven sections. First, aggregate trends in R&D expenditures are discussed and analyzed. That section is followed by more detailed information on two of the major R&D-performing sectors: industry and the Federal Government. Also covered in this section are collaborative R&D activities and R&D data for federally funded research and development centers (FFRDCs).

The third section is devoted to the most recent data on the geographic distribution of R&D expenditures, including information on state and Federal cooperative technology programs. Defense-related S&T issues are discussed in the following section.

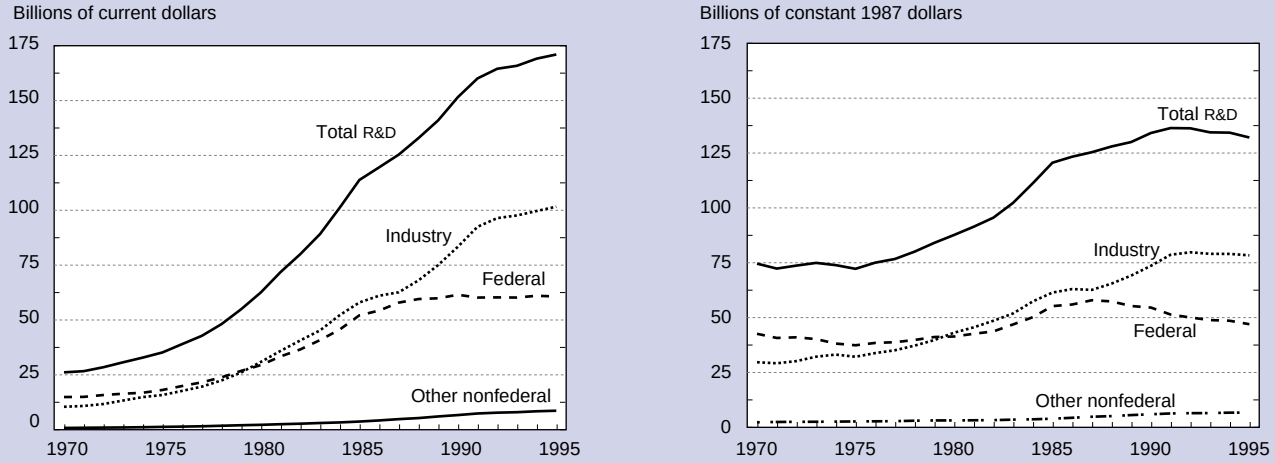
International R&D comparisons are covered in the last three sections, including analyses of absolute levels of spending by country, R&D-to-gross-domestic-product (GDP) ratios, government focus by national objective, and the internationalization of R&D and technology.

National Trends in Research and Development Expenditures

Total U.S. investment in R&D reached an estimated $171 billion in 1995, up 1 percent in current dollars over the estimated 1994 level, but down 2 percent after adjustment for inflation.[1] Growth in R&D funding in the United States has not kept pace with inflation. R&D expenditures have been shrinking in recent years, although the annual decreases have been small, averaging an estimated 0.8 percent between 1991 and 1995. Prior to 1991, the last time there was a constant-dollar reduction in total U.S. R&D spending was in 1975. Between 1975 and 1982, the inflation-adjusted annual rate of increase averaged 4.1 percent; this rate rose to 8.1 percent between 1982 and 1985, and slowed to 2.1 percent in the years leading up to 1991. (See figure 4-1 and appendix tables 4-3 and 4-4.)

[1]Throughout this chapter, current funding or expenditure data are presented in nominal dollars. In keeping with U.S. Government and international standards, R&D trend data usually are deflated to 1987 constant dollars using the Gross Domestic Product implicit price deflator and are so indicated. (See appendix table 4-1.) Since GDP deflators are calculated on an economy-wide rather than R&D-specific basis, their use more accurately reflects an "opportunity cost" criterion, rather than a measure of cost changes in doing research. The constant dollar figures reported here thus should be interpreted as real resources foregone in engaging in R&D rather than in other activities such as consumption or physical investment. Broad-based deflators—such as the GDP deflator —are, however, quite useful in approximating changes in aggregate R&D costs (Jankowski, 1993). They are undoubtedly much *less* appropriate for calculating real R&D expenditures at a more disaggregated level. Further, comparisons in this chapter of U.S. and international R&D expenditure data are based on reported R&D investments converted to U.S. dollars with purchasing power parity (PPP) exchange rates. (See appendix table 4-2.) Although PPPs are not equivalent to R&D exchange rates per se, they better reflect differences in countries' laboratory costs than do market exchange rates.

Figure 4-1.
National R&D funding, by source



See appendix table 4-4.

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National Research and Development Trends by Source of Support and Performing Sector

There are two major sources of financial support of R&D activity—industry and the Federal Government. Together, these two sectors supply approximately 95 percent of all money spent on R&D performed in the United States. The remaining 5 percent is provided primarily by universities and colleges and nonprofit organizations.[2] (See figure 4-2 and appendix table 4-4.)

In addition to financing R&D, industry and the Federal Government are major R&D performers. A third sector, academia, also plays a major role in the performance of research. Industry, the Federal Government, and academia are responsible for 70 percent, 10 percent, and 13 percent, respectively, of national R&D investment. Two other groups—nonprofit organizations and university-administered FFRDCs[3]—each account for 3 percent of total R&D spending.

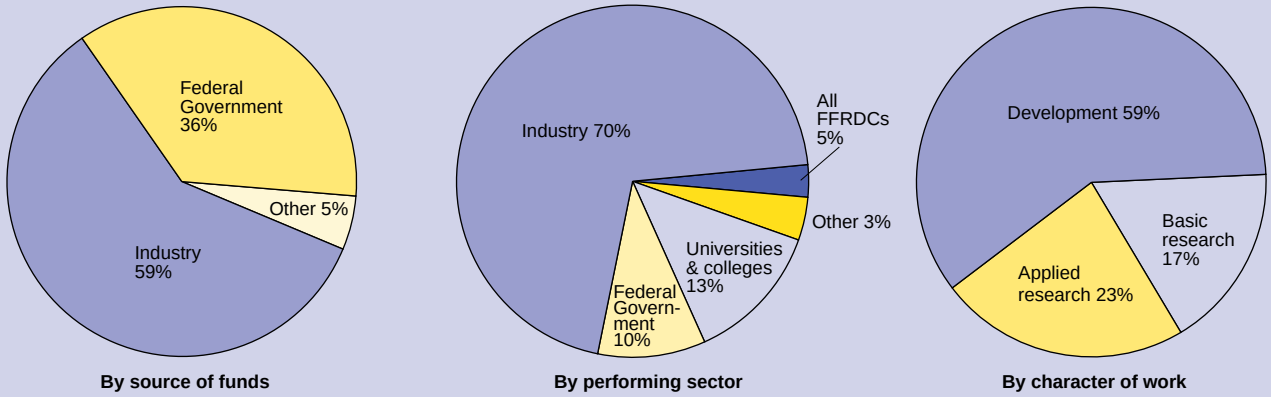
Sources of R&D Support

The industrial sector is both the largest source of R&D funds and the leading R&D-performing sector in the United States. In 1995, companies provided an estimated $101.7 bil-

[2]R&D performed by state and local governments is not included in the national R&D totals. In 1987, R&D performance by these entities was estimated to be less than $1 billion.

[3]FFRDCs are organizations exclusively or substantially financed by the Federal Government to meet particular requirements or provide major facilities for research and associated training purposes. Each center is administered by an industrial firm, an individual university, a university consortia, or a nonprofit organization. (See Federally Funded Research and Development Centers in this chapter.)

Figure 4-2.
National R&D expenditures: 1995



NOTE: Total may not equal 100 percent as a result of rounding.

See appendix tables 4-3, 4-4, 4-5, 4-6, and 4-7.

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Text table 4-1.
U.S. R&D expenditures, by performing sector and source of funds: 1995

Performing sector	Total	Sources of funds: Industry	Federal Government	Universities and colleges[1]	Other nonprofit institutions	Percent distribution, performers
	Millions of dollars					
Total	171,000	101,650	60,700	5,500	3,150	100.0
Industry	119,600	99,300	20,300	–	–	69.9
Industry-administered FFRDCs[2]	1,800	–	1,800	–	–	1.1
Federal Government	16,700	–	16,700	–	–	9.8
Universities and colleges	21,600	1,500	13,000	5,500	1,600	12.6
University-administered FFRDCs[2]	5,300	–	5,300	–	–	3.1
Other nonprofit institutions	5,100	850	2,700	–	1,550	3.0
Nonprofit-administered FFRDCs[2]	900	–	900	–	–	0.5
Percent distribution, sources	100.0	59.4	35.5	3.2	1.8	

FFRDC = federally funded research and development center; – = unknown, but assumed to be negligible

NOTE: Data are estimated.

[1]Includes an estimated $1.6 billion in State and local government funds provided to university and college performers.

[2]FFRDCs conduct R&D almost exclusively for use by the Federal Government. Expenditures for FFRDCs therefore are included in Federal R&D support, although some nonfederal R&D support may be included.

See appendix tables 4-3 and 4-4.

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lion to support R&D performed in the United States, or 59 percent of the national total. Of this amount, $99.3 billion financed work performed in-house; the remaining $2.4 billion was used to support R&D activities undertaken at academic institutions and nonprofit organizations. (See appendix tables 4-3 and 4-4 and text table 4-1.)

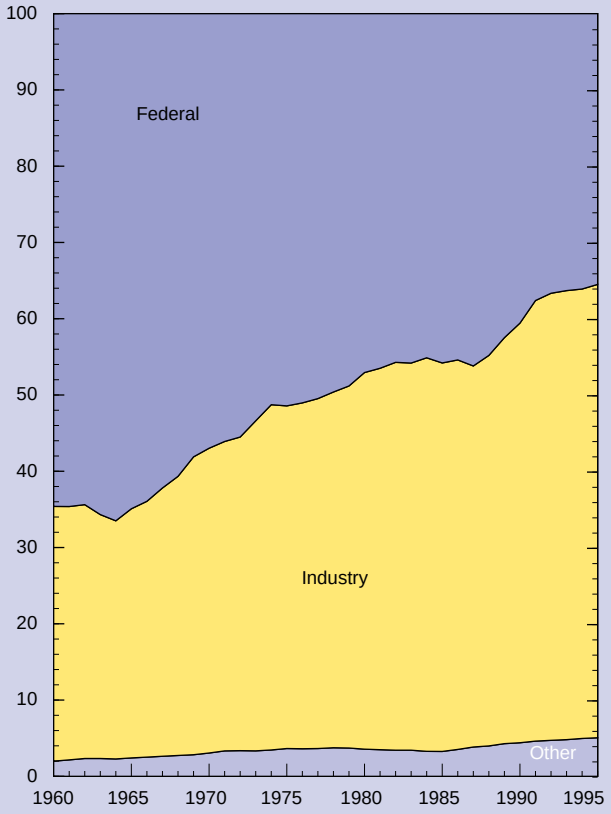
Industry has not always been the largest source of R&D dollars in the United States. It took over that role from the Federal Government in 1980. (See figure 4-1 and appendix table 4-4.) In 1970, Federal agencies supplied 57 percent of all dollars spent on R&D in the United States. During the ensuing decade, however, industry R&D support grew at a faster pace than that of the Federal Government, so that in 1980 industry became the leading source of R&D dollars. In the early and mid-1980s, the industry share of the R&D total was fairly stable, hovering slightly above the 50-percent mark. In 1987, that proportion began to rise again, 1 or 2 percentage points per year. The most recent data show industrial firms providing $3 out of every $5 spent on R&D in the United States. (See figure 4-3 and appendix table 4-4.)

In recent years, industry R&D financing almost—but not quite—kept pace with inflation. Between 1975 and 1985, industrial R&D funding more than tripled, increasing at an average constant-dollar rate of 6.7 percent per year. In the late 1980s, the annual rate of increase slowed to 5.9 percent, the average registered between 1987 and 1991. According to recent estimates, there has been no real growth since 1993. (See figure 4-1 and appendix table 4-4.)

The Federal Government, the other major source of R&D support in the United States, provided an estimated

Figure 4-3.
National R&D expenditures, by source of funds

Percent of total R&D spending



See appendix table 4-4.

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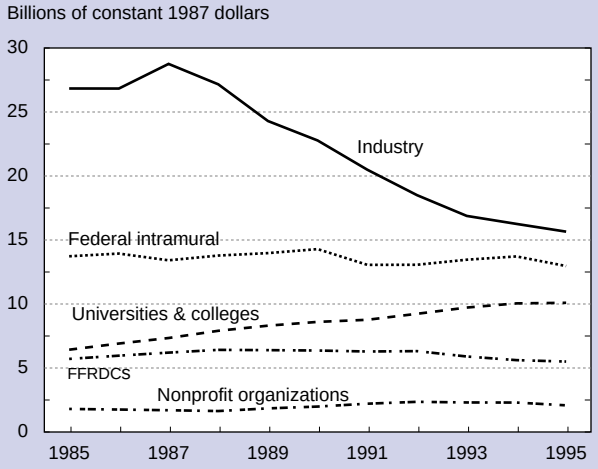
Figure 4-4.
Federal R&D support, by performing sector



See appendix table 4-4.

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$61 billion in R&D funds in 1995, or 36 percent of the national total. Most Federal R&D dollars are not used in Government-owned laboratories, but instead are used to finance R&D performed in other sectors. (See figure 4-4 and appendix table 4-3.) For example,

- Industry received an estimated $20.3 billion in Federal R&D support in 1995, mainly to finance defense-related R&D performed under contract to the Department of Defense (DOD) and the Department of Energy (DOE).
- Academic institutions acquired an estimated $13.0 billion in Federal R&D support in 1995; almost all of these funds supported basic and applied research in the biological, physical, and social sciences and engineering. In addition to the acquisition of new knowledge and breakthrough discoveries, research conducted on university and college campuses provides another widely acknowledged benefit: it plays a key role in training the next generation of scientists and engineers. (See chapter 2, Higher Education in Science and Engineering, and chapter 5, Academic Research and Development: Infrastructure and Performance.)
- FFRDCs and other nonprofit organizations received an estimated $8.0 billion and $2.7 billion, respectively, in Federal R&D funds in 1995.

Like industry R&D support, there has been a lack of growth in Federal R&D funding in recent years. The trend started in the late 1980s, earlier than the industry slowdown, and the cutbacks were larger. Between 1987 and 1995, Federal R&D support fell at an average annual constant-dollar rate of 2.6 percent. In addition, while industry's share of the national total has been climbing, the Federal share has been eroding—from 46 percent of the total in 1987 to an estimated 36 percent in 1995. (See figures 4-1 and 4-3 and appendix table 4-4.)

National Research and Development Trends by Performing Sector

Industry

Industry has always been the largest R&D performing sector, by far. Because companies perform a substantial amount of R&D for the Federal Government, the industrial sector is responsible for $7 out of every $10 spent annually on R&D conducted in the United States. In 1995, R&D performed in U.S. industrial laboratories is estimated to have cost $119.6 billion.

After 16 years of continuous growth during the late 1970s and throughout the 1980s, industrial R&D performance underwent a turnaround in the early 1990s. Industrial R&D performance fell at an estimated average annual rate of 1.5 percent per year in constant dollars between 1991 and 1995. The cutbacks can be considered a continuation of a slowdown that began in the late 1980s. Between 1985 and 1991, there was a marked reduction in the rate of expansion of industrial R&D programs. During that period, the annual real rate of increase averaged only 1.8 percent, compared with the 6.1-percent rate registered during the late 1970s and early 1980s. (See figure 4-5 and appendix table 4-4.)

The slowdown in industrial R&D performance is largely attributable to Federal R&D cutbacks. Government-funded R&D performed by companies dropped from $30.8 billion in 1987 to an estimated $22.1 billion in 1995. (See figure 4-6 and appendix tables 4-8, 4-9, and 4-10.) As a result, the Federal share of total industrial R&D expenditures declined from nearly one-third of the total in 1987 to 17 percent in 1995.

Data for the years after 1985 indicate industrial R&D performance continuing to increase, but only in the service sector.[4] During the last part of the 1980s, R&D conducted in the manufacturing sector slowed to a standstill, the beginning of a trend that has continued into the 1990s.

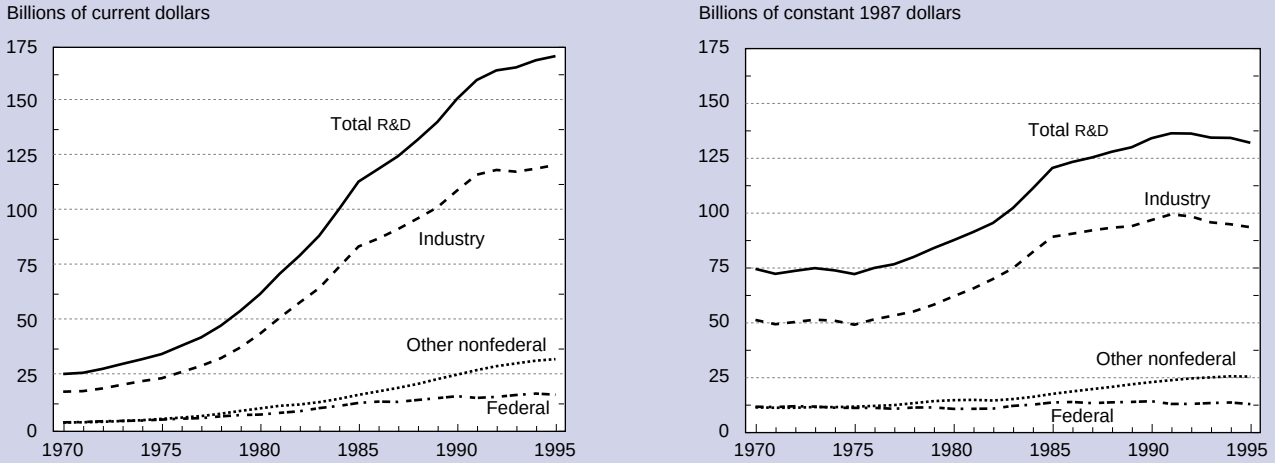
Several reasons have been cited for the lack of growth in some companies' R&D programs in the mid-1990s. These include corporate downsizing, decentralization (i.e., a shifting of R&D activity from corporate laboratories to individual business units), and increasing collaboration among industrial firms and with partners in academia, government, the nonprofit sector, and in other countries (Institute for the Future, 1995; Bean, 1995; Wolff, 1995). (See Collaboration Among Firms and with Other Organizations in this chapter.)

Academia

Academia is a distant second to industry in terms of R&D performance, with total expenditures amounting to an estimated $21.6 billion in 1995, or 13 percent of the national total. Until 1990, the academic sector ranked

[4]Because of ongoing improvements in NSF's annual Survey of Industrial Research and Development aimed at better coverage of the nonmanufacturing sector, it is not possible to determine how much of the increase in R&D spending in the service sector is real and how much is attributable to better coverage of the sector (Pollak, 1991; SRS, 1994).

Figure 4-5.
National R&D funding, by performer



See appendix table 4-4.

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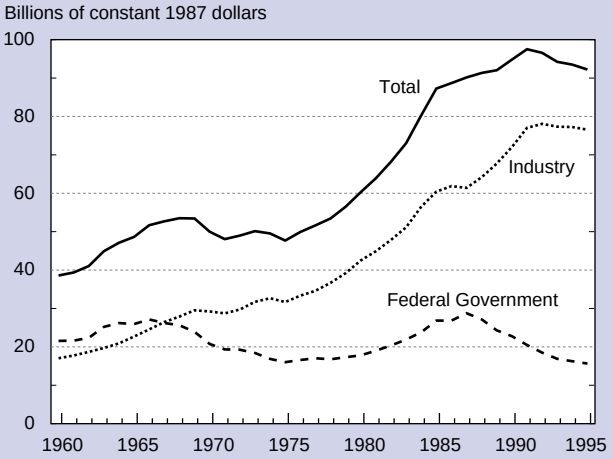
Figure 4-6.
U.S. industrial R&D expenditures, by source of funds



See appendix tables 4-8, 4-9, and 4-10.

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third in total R&D performance in the United States, after industry and the Federal Government. Since 1985, however, the rate of increase in R&D performed at universities and colleges has been higher than that of the Federal Government. As a result, these institutions moved into second place in 1990, behind industry. (See figure 4-5 and appendix table 4-4.)

Academia is the only R&D-performing sector not to have suffered a constant-dollar decline in R&D performance during the 1990s. However, the annual real rate of growth has been falling fairly steadily since 1986, dropping from a nearly 10-percent increase in 1985–86 to a less than 1-percent change estimated for 1994–95.

Most of the research performed on university and college campuses is funded by the Federal Government. In 1995, Federal agencies provided an estimated $13.0 billion, or 60 percent of the total funding for university research. Academic institutions supplied an estimated $3.9 billion of their own funds, nonfederal sources (i.e., state and local governments) and nonprofit organizations each contributed $1.6 billion, and industry provided $1.5 billion. R&D support from each of these sectors rose during the 1990s, with Federal agencies registering the largest absolute and percentage increase—35 percent in current dollars or 3.2 percent per year in real terms. Federal R&D support to academia has been increasing continuously since 1982, even after adjustment for inflation. (See figure 4-4 and appendix table 4-3.)

The expansion in Federal support of research performed at colleges and universities is the only exception to what has otherwise been a shrinking pool of (inflation-adjusted) Federal R&D financial resources. As mentioned earlier, the largest part of the Federal R&D budget—that part devoted to defense and national security—has been on a strict diet since the late 1980s. (Defense downsizing has had the greatest impact on the military's industrial contractors and on the nonprofit organizations that conduct R&D for DOD and DOE.)

Federal Agencies

Federal entities spent an estimated $16.7 billion on intramural R&D in 1995, 10 percent of national R&D performance. Most Federal R&D monies are not spent in federally run facilities, but in other sectors. Federal intramural R&D has shown very little change in real terms since 1985. There have been some noticeable year-to-year gains and losses, but these changes were usually counterbalanced in subsequent years. For example, an 8.6-percent real decline in Federal R&D performance between

1990 and 1991 was partially offset by gains during the following 2 years. Federal R&D performance is estimated to have dropped 5.5 percent in constant dollars between 1994 and 1995. (See appendix table 4-3 and figure 4-5.)

Research and Development Support and Performance by Character of Work

The traditional way to analyze trends in R&D performance is to examine the amount of funds devoted to basic research, applied research, and development. (See *Definitions.*) These terms are convenient because they correspond to popular models that presume that innovation occurs in a straight-line progression through three stages: scientific breakthroughs from the performance of basic research lead to applied research, which, in turn, leads to development or the application of applied research to commercial products and processes. Although the simplicity of this approach makes it appealing to policymakers, the traditional categories of basic research, applied research, and development are somewhat murky and, thus, are not always ideal in describing the complexity of the relationship between science, technology, and innovation in the real world.

Over the years, alternative models have been developed in an attempt to capture the true complexity of the innovation process. One that has recently received a favorable amount of attention is a model developed by Donald Stokes of Princeton. (See *Alternative Models of R&D and Innovation.*) Although this and other models may provide a more realistic depiction of the innovation process than does the linear model, they are probably too complicated to be used in collecting comparable and reliable data for policymaking purposes. Therefore, the practice of categorizing R&D expenditures into basic research, applied research, and development for analytical and policymaking purposes is unlikely to be abandoned anytime soon.

Most R&D dollars—an estimated $101.7 billion in 1995, or 59 percent of the total—are spent on development. Applied research accounted for an estimated 23 percent, and basic research, 17 percent. (See figure 4-2.) These proportions tend to be fairly stable over time, although there are usually slight movements from year to year. For example, the proportion of total R&D funds devoted to development has been falling for the past decade, declining from 65 percent in 1985, while funds used for basic research increased from 12 percent to 17 percent.[5] These trends are not unexpected given that (1) most military-related R&D is development, and defense appropriations declined during the period, and (2) about half the Nation's basic research is conducted on university and college campuses. As mentioned previously, R&D conducted in the academic sector has been relatively healthy compared with R&D performed in the other sectors.

[5]Some of this increase may simply be a result of changes in the industry R&D survey. See Science Resources Studies Division (1995b).

Definitions

The National Science Foundation uses the following definitions in its resource surveys.

Basic research: The objective of basic research is to gain more comprehensive knowledge or understanding of the subject under study, without specific applications in mind. In industry, basic research is defined as research that advances scientific knowledge but does not have specific immediate commercial objectives, although it may be in fields of present or potential commercial interest.

Applied research: Applied research is aimed at gaining knowledge or understanding to determine the means by which a specific, recognized need may be met. In industry, applied research includes investigations oriented to discovering new scientific knowledge that has specific commercial objectives with respect to products, processes, or services.

Development: Development is the systematic use of the knowledge or understanding gained from research directed toward the production of useful materials, devices, systems, or methods, including the design and development of prototypes and processes.

Budget authority: Budget authority is the authority provided by Federal law to incur financial obligations that will result in outlays.

Obligations: Federal obligations represent the amounts for orders placed, contracts awarded, services received, and similar transactions during a given period, regardless of when the funds were appropriated or payment required.

Outlays: Federal outlays represent the amounts for checks issued and cash payments made during a given period, regardless of when the funds were appropriated or obligated.

Basic Research

In 1995, an estimated $29.6 billion was spent on basic research performed in the United States. Most of that amount—$17.1 billion or 58 percent of the total—was supplied by the Federal Government. Industrial firms provided $7.5 billion or 25 percent of the total; universities and colleges, $3.4 billion; and nonprofit organizations, $1.6 billion. (See figure 4-7 and appendix table 4-5.)

Although the Federal Government is the leading supplier of funds, the academic sector is the largest performer of basic research, with expenditures totaling an estimated $14.5 billion in 1995. Of that amount, an estimated $9.2 billion were Federal funds. Far smaller amounts were supplied by the universities themselves, state and local governments, industry, and nonprofit organizations. Federal funding of basic research performed in the academic sector increased during the 1990s, but the average annual real rate of increase—

Alternative Models of R&D and Innovation

The relationship between science and technology is usually described by referring to a model that depicts innovation as a three-step, linear process. The three steps are basic research, applied research, and development. Vannevar Bush (1945), in his landmark treatise, *Science—The Endless Frontier*, used this linear model as the framework for explaining and, subsequently, justifying an expanded role for the Federal Government in supporting scientific research. The simplicity of this model makes it particularly appealing to—and popular among—policymakers.

Experts who have studied the innovation process, however, usually favor alternative, more complex explanations of the relationship between science and the commercialization of new technology, including the chain link model, (Kline and Rosenberg, 1986; OECD, 1992) which is an interactive model with feedback loops. As evidence of the inadequacies of the linear model, these experts cite real world examples that demonstrate that technological breakthroughs are just as likely to precede, as to stem from, basic research.

In a forthcoming book, *Pasteur's Quadrant* (in press), Donald Stokes describes a new model that holds great promise for further discussions of this issue. The starting point for his approach is the work of the great scientist Louis Pasteur. Stokes writes that:

> The rise of microbiology in the late 19th century is a conspicuous example of how large a role considerations of use can play in the advance of basic science. Pasteur sought a fundamental understanding of the process of disease—and of the other microbiological processes he discovered. But he wanted this to deal with…anthrax in sheep and cattle, cholera in chickens, spoilage in milk and wine and vinegar, and rabies in animals and human beings.

Pasteur's work was both basic and applied at the same time. The experiments he conducted yielded both breakthroughs in scientific understanding and practical applications. Therefore, his work was at odds with the linear model.

Stokes cites numerous other major scientific achievements, including the work of Faraday and Kelvin, as being motivated by both fundamental understanding and potential use.

Stokes suggests replacing the linear model with one that captures the inherent overlap between basic and applied research. Stokes' model describes several different categories of research: pure basic research (the work is inspired by the quest for basic understanding but not by potential use); purely applied research (the work is motivated only by potential use); and strategic research (research that is inspired by both potential use and fundamental understanding).

Stokes' work is facilitating understanding of basic research as having potential value in terms of practical application beyond that gained from pure science. He writes, "We will be more likely to meet essential societal needs, including competitiveness in the global economy, if we creatively link the dual trajectories of basic science and technological innovation." Additionally, Organisation for Economic Co-operation and Development standard definitions now differentiate between two types of basic research: "pure basic research," and "oriented basic research." These new approaches help to convey the concept that basic research can be extremely useful, regardless of whether or not the potential use is known at the time the research is being conducted.

3.2 percent—was about half the rate registered between 1985 and 1991.

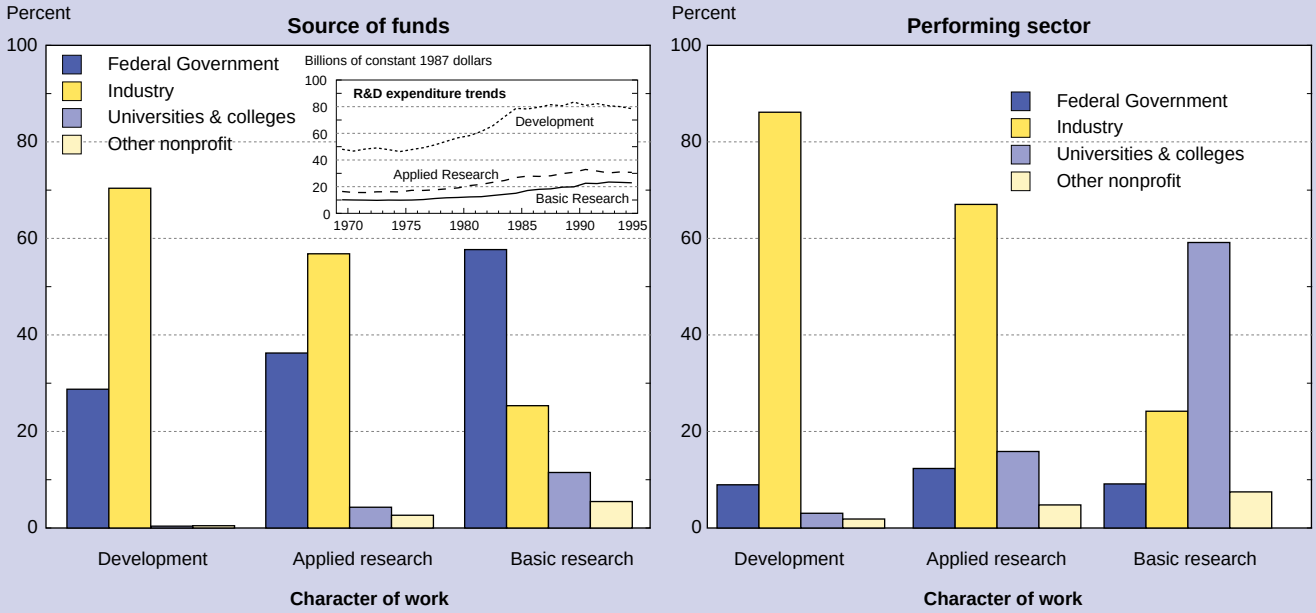
An estimated 6 percent of the funds spent on basic research in academic institutions in 1995 came from industrial sources. Industry's support of research conducted on university and college campuses has always been a small, but growing, component of the academic research portfolio.[6] Industry officials have tapped this resource not only because their companies benefit from the results of the research they sponsor, but also because they recognize that such research opportunities are a crucial component in training future scientists and engineers, many of whom will one day be working in their laboratories. In addition, companies are depending on universities and the Federal Government to maintain basic research activities because their own programs are being curtailed.

Industrial firms spent an estimated $6.2 billion of their own and nearly $1 billion in Federal funds on basic research undertaken in their laboratories in 1995. Basic research constitutes an estimated 6 percent of total industrial R&D performance. Between 1991 and 1995, the amount of funds spent by industry to perform basic research declined at an average annual, constant-dollar rate of 4.6 percent.

In the past few years, several companies' central research facilities have been dismantled, part of an ongoing shift in emphasis away from fundamental research and toward applied research and development that has

[6]See chapter 5, Academic Research and Development: Infrastructure and Performance, for a discussion of the increasing number of scientific journal articles with industry–university co-authorship.

Figure 4-7.
National R&D expenditures, by source of funds, performing sector, and character of work: 1995



NOTE: Funds for federally funded research and development center performers are included in their affiliated sectors.

See appendix tables 4-5, 4-6, and 4-7.

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occurred largely in reaction to growing international competition in the high-tech arena. (See chapter 6, Technology Development and Diffusion.) In addition, applied research and development are increasingly being conducted within individual business units in a concerted effort to speed commercialization of new technology (Bean, 1994).

An estimated $2.7 billion was used to finance basic research performed in federally-run laboratories in 1995. Funding of Federal intramural basic research (about 16 percent of total Federal intramural R&D) has remained fairly constant in real terms since 1983.

Applied Research

Nearly $40 billion, or about 23 percent of total R&D, was spent on applied research performed in the United States in 1995. (See figure 4-7 and appendix table 4-6.)

Industry is both the leading source of applied research support and the leading performer. In 1995, companies were the source of an estimated $22.6 billion spent on applied research. The proportion of all applied research funds originating in industry has been increasing steadily for the past 25 years—from 42 percent of the total in 1970 to 57 percent in 1995. At the same time, the Federal Government's share of the total has been falling—from 54 percent in 1970 to an estimated 36 percent in 1995. Both industry and the Government have curtailed their support of applied research projects in the 1990s. In real terms, the average annual rates of decrease were 1.8 percent and 2.0 percent, respectively, between 1991 and 1995.

Of the major R&D-performing sectors, industry is the only one to report a constant-dollar decline in applied research performance—averaging 3.1 percent in real terms between 1991 and 1995. Funding of applied research performed at Federal facilities and at academic institutions grew at annual rates averaging 2.1 percent and 2.3, respectively, during the same period.

Internally financed applied research was relatively flat during this period, so the industrial decline is entirely attributable to a reduction in Federal support, although the latter accounts for less than 20 percent of the money spent by companies on applied research. The recent decline in Federal support of industry-performed applied research presents a marked contrast to the 1980s. Between 1979 and 1990, funds from Federal agencies quadrupled, reaching an all-time high of $6.4 billion in 1990. Five years later, Federal funding of applied research conducted in industrial laboratories was down to an estimated $4.9 billion.

Despite the recent cutbacks, industrial firms have been the most prominent players in applied research performance during the past 25 years. In the late 1980s, more than 70 percent of the Nation's applied research was performed in industrial laboratories. That share has receded somewhat—to 67 percent—in recent years.

Along with industry, academic institutions have assumed a larger role in the performance of applied research. Their share of the total amount spent on applied research has been rising gradually for the past 25 years; they are now the second largest performer of

applied research, accounting for an estimated 14 percent of the total spent in 1995.

Contrary to the overall trend, there was an upsurge in applied research performed on university and college campuses in the 1990s. Led by an increase in Federal support (which accounts for about half the total), spending rose 25 percent—from $4.3 billion in 1990 to $5.5 billion in 1995.

In contrast, the role of Federal intramural applied research has dwindled considerably in the past 25 years. In 1995, Federal agencies spent an estimated $4.9 billion to perform applied research in their own installations; this amount accounted for only 12 percent of the national total, down from 23 percent in 1970.

Development

Six out of every 10 dollars spent on R&D in the United States are spent on development. (See figure 4-7 and appendix table 4-5.) An estimated $101.7 billion was used to finance the development of new and improved products, processes, and services in 1995; this amount was about 2 percent below the 1994 level, after adjustment for inflation. Development funding has been falling in real terms almost continuously since 1990, but the decreases have been small, averaging 1.2 percent between 1990 and 1995. This decline is largely attributable to the post-Cold-War curtailment in defense spending. Federal support of development projects has been falling in real terms since 1987.

Like applied research, industry is both the leading provider of development funds and the major performer. Industry became the largest source of development funds in 1974, overtaking the Federal Government in that year. In 1995, industrial firms were the source of an estimated $71.6 billion, or about 70 percent, of the total spent on development in the United States. All but $280 million of those funds were spent in companies' own laboratories. The Federal share of development R&D funds is now estimated to be less than 30 percent of the total, down from more than 40 percent during the late 1970s and 1980s. (See appendix table 4-7.)

Almost all development dollars are spent by industrial firms. Advancing and applying new technologies are activities undertaken almost exclusively in the private, profit-making sector. The most recent data show that the other R&D-performing sectors, including the Federal Government, universities and colleges, and nonprofit organizations, are responsible for spending only 14 percent of the national total. Of the estimated $87.6 billion expended by industry on development in 1995, an estimated $16.3 billion, or 19 percent of the total, came from Federal contracts.

Federal support of development projects conducted in industrial laboratories increased dramatically between 1980 and 1988, doubling from $11.8 billion to an all-time high of $25.1 billion during that period. Much of that increase is attributable to the massive defense buildup during the Reagan era, when a wide array of new, highly sophisticated defense systems and weapons, including the Strategic Defense Initiative, went on the drawing board. Since 1988, there has been a major curtailment in Federal funding; a 35-percent drop was registered between 1988 and 1995.

In contrast to the decline in Federal support of industry-performed development activities, funding from other sources (essentially industry's own funds) rose during the 1990s, from $59.4 billion in 1990 to $71.3 billion in 1995, an average annual real increase of about 1 percent per year.

The Federal Government is a distant second to industry in terms of development performance. Federal agencies spent an estimated $9.1 billion in 1995, about a billion dollars below the 1990 level. In real terms, Federal intramural performance of development fell at an average annual rate of 4.7 percent between 1990 and 1995.

Research and Development Patterns by Sector

In this section, industry's and the Federal Government's investment in R&D are examined in greater detail. (See chapter 5, Academic Research and Development: Infrastructure and Performance, for additional information pertaining to R&D performance in the academic sector.)

Industrial Research and Development

Industry is, by far, the largest R&D-performing sector. In 1995, companies spent an estimated $99.3 billion of their own (and other nonfederal) and $20.3 billion in Federal funds on R&D performed in U.S. laboratories. (See appendix table 4-3.) Of the latter, $1.8 billion was spent on R&D performed at FFRDCs. A closer look at the most recent industrial R&D data reveals that, during the late 1980s and early 1990s, cutbacks occurred in two areas: (1) inflation-adjusted dollars invested in R&D by companies classified in manufacturing industries and (2) Federal funding of industry-performed R&D.

These trends were partially offset by increased R&D investment by companies classified in the service sector, but overall R&D spending declined, in real terms, during the 1990s. (See appendix table 4-8.) The following sections contain more detailed information about these and other trends in industrial R&D spending.

Information from selected large industrial R&D performers indicate that industry expects some improvement in 1996 (IRI, 1996). For additional information about the current climate for industrial R&D, see "*Biggest" Problems Facing Technology Leaders* and *Industrial Research and Development Planning Environment.*

"Biggest" Problems Facing Technology Leaders

The Industrial Research Institute (1995a), a trade association with a membership that includes R&D directors from most of the largest U.S. R&D-performing companies, conducts an annual poll in which members are asked to identify the "biggest" problems they face. According to responses to the most recent poll, conducted in the spring of 1995, the most serious problems facing technology leaders are

1. Measuring and improving R&D productivity/effectiveness,
2. Balancing long-term/short-term R&D objectives/focus,
3. Reducing cycle-time R&D,
4. Making innovation happen,
5. Integrating strategic technology planning with corporate strategic planning,
6. Managing R&D for business growth,
7. Gaining access to external sources of technology,
8. Managing the R&D portfolio,
9. Organizing and determining the role of R&D in centralized and decentralized businesses, and
10. Integrating the enterprise (coordinating R&D with all other corporate activities).

Research and Development in Manufacturing Versus Nonmanufacturing Industries

Probably the most striking trend in industrial R&D performance in recent years is the growing prominence of the service sector. Until fairly recently (the late 1980s), little attention was paid to R&D conducted by nonmanufacturing companies, largely because service sector R&D activity was minuscule compared with the R&D operations of companies classified in manufacturing industries.

Prior to 1983, nonmanufacturing industries accounted for less than 5 percent of the industry total. A decade later, the R&D landscape looked very different. Between 1983 and 1993, there was a steady increase in the proportion of total industrial R&D performed by companies classified in service industries. (See figure 6-10 in Chapter 6, *Technology Development and Diffusion*.) In 1993, nonmanufacturing firms were responsible for more than one-quarter of all industrial R&D performed in the United States. That year, their expenditures amounted to $25.5 billion in company and other nonfederal funds and $5.7 billion in Federal funds. (See appendix table 4-11.)

Three industry groupings account for the bulk of R&D performed in the service sector:

- Computer programming, data processing, other computer-related engineering, architectural, and surveying services accounted for $7.7 billion in nonfederal R&D expenditures in 1993;
- Communication services accounted for $4.2 billion; and
- Research, development, and testing services accounted for $1.4 billion.

Between 1987 and 1993, the share of all nonfederal R&D money received by each of these industries more than doubled. (See text table 4-2.)

A sizable portion of the R&D dollars in two of these industries—computer software and communication services—was spent by companies formerly classified in manufacturing industries. Given the growing importance of computer software (relative to hardware) and other information technologies, this shift from manufacturing to nonmanufacturing is not unexpected.

In addition, because the United States invests a relatively large share of its resources in health care, about 13.9 percent of GDP in 1993 (Department of Health and Human Services, 1993), the increasing importance of R&D laboratories in the Nation's industrial R&D portfolio is also predictable. It can be attributed, in large part, to major advancements in research on the human body, the establishment and growth of a variety of medical research facilities, and the maturing and success of the biotechnology industry.

Concurrent with the growing visibility of R&D in the service sector, R&D performed by manufacturing industries lost some of its pre-eminence. Still, the manufacturing sector continues to dominate the R&D spectrum.

In 1993, the six largest manufacturing industries, in terms of companies' own (and other nonfederal) R&D expenditures in the United States were

Text table 4-2.
Share of total company and other nonfederal funds, by selected R&D-performing industries

	1987	1993
	—Percent—	
All manufacturing industries	91.6	73.3
Chemicals and allied products	15.3	17.5
Petroleum refining and extraction	3.0	2.2
Machinery	17.2	8.6
Electrical equipment	17.0	11.8
Transportation equipment	21.9	17.9
Instruments	8.1	7.9
All nonmanufacturing industries	8.4	26.7
Communication services	1.8	4.4
Computer programming and other related services	3.6	8.1
Research, development, and testing services	0.1	1.5

SOURCE: Science Resources Studies Division, National Science Foundation, *Research and Development in Industry: 1993* (Arlington, VA: NSF, forthcoming).

See appendix table 4-9

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Industrial Research and Development Planning Environment

Every 5 years, the Industrial Research Institute prepares a strategic plan (Industrial Research Institute, 1995b). According to the most recent document, the 1996–2000 planning environment will be shaped by the following S&T trends:

1. Technology development will continue to occur increasingly outside of the United States. Cooperative means to monitor, develop, or acquire technology worldwide will become increasingly important.
2. Successful corporations will view intellectual property and technology as a strategic resource to be created, acquired, shared, protected, or otherwise traded to gain worldwide market advantage.
3. R&D organizations will be required to manage their activities against quantifiable business goals and objectives in the same manner as other operating functions of the company.
4. Pressures for short-term results from U.S. industrial research laboratories will continue; financial and analytical tools will be used increasingly to assess and communicate the potential rewards and risks of longer range programs; reduced support for directed basic research can be expected to continue.
5. R&D managers will face growing challenges to retain the best employees for long-term careers in technical roles and to manage a diversified, multicultural workforce. Fatter organizational structures will limit opportunities, and leaner organizations will require fewer employees to accomplish more.
6. Shifts between centralized, decentralized, and hybrid organizations will continue, and the expansion of knowledge will accelerate.
7. The image of S&T will require regular attention to overcome negative public perceptions.
8. Changing world political and economic order will result in shifts in Federal R&D spending patterns and in the nature of the Federal laboratory establishment. Private-sector funding of academic research will continue to grow, while Government funding will be uncertain.
9. Issues of quality, environment, health, and safety will be the impetus for a new level of creativity in R&D to permit industrial expansion to occur within the context of a more highly regulated climate.
10. R&D can no longer be looked at in isolation from the larger activity of technology commercialization or innovation.

- Transportation equipment, $17.1 billion;
- Chemicals and allied products (which includes the drugs and medicines industry), $16.7 billion;
- Electrical equipment, $11.3 billion;
- Machinery (which includes companies classified as computer hardware manufacturers), $8.2 billion;
- Professional and scientific instruments, $7.5 billion; and
- Petroleum refining and extraction, $2.1 billion.

These six industries accounted for 90 percent of all nonfederal R&D funds spent by companies classified as manufacturing industries in 1993, the same percentage they held in 1987. (See appendix table 4-9.) What has changed is their share of all industrial R&D dollars. That proportion fell from 83 percent in 1987 to 66 percent in 1993.

The share of total nonfederal R&D funds held by five of the six industries fell during the late 1980s and early 1990s. Only the chemicals and allied products industry had an increase in its share of the total—from 15 percent in 1987 to 17 percent in 1993. The machinery industry's decline was particularly acute—from 17 percent of the total to 9 percent. (In 1987, almost all computer manufacturers were included in this group; some of these companies were reclassified into service industries in subsequent years.) Between 1987 and 1993, the chemicals and machinery industries switched places—the chemicals industry became the second largest R&D performing industry (it had been fourth), and the machinery industry dropped from second to fourth. Although the rankings of the other major R&D-performing manufacturing industries stayed the same, the share of the national R&D total held by firms classified in the electrical equipment industry declined from 17 percent to 12 percent, and the transportation equipment industry share dropped from 22 percent to 18 percent.

Research and Development Expenditures by Size of Company

In 1993, 125 companies with more than 25,000 employees spent more than $1 million each on R&D in the United States (SRS, 1995b). Prior to 1990, this group of companies accounted for more than half the nonfederal R&D total. That share has fallen below 50 percent because the R&D expenditures of firms with fewer than 500 employees have been increasing faster than those of companies in the other size-groups.[7] Small firms' share of the total increased from 10 percent in 1990 to 15 percent in 1993. (See appendix table 4-9.)

[7]The apparent increase in small companies' R&D performance may also be attributable to expanded coverage of this group in NSF's annual survey of industrial research and development.

U.S. industrial R&D expenditures are heavily concentrated in a relatively small number of firms. In 1993, the 4 largest R&D performing companies (in terms of nonfederal funds) accounted for 17 percent of the total amount spent; the 20 largest, 33 percent; and the 200 largest, 71 percent. (See appendix table 4-12.)

Over a 10-year period, 1984–94, some major membership changes occurred in the annual list of 100 leading R&D-performing companies according to Standard & Poor's Compustat Services, Inc.[8] (See appendix table 4-14.) The four largest R&D-performing companies, however, were the same in both years (although their order changed). That may be one of the few constants revealed by comparing the lists from 1984 and 1994. There were some major changes in rankings among the remaining 96 entries. For instance,

- Six companies moved into spots 5 through 10, and the former occupants of those places moved down. Among the six new entrants, Motorola made the largest leap; it moved from 21st to 6th place. Of the companies that fell out of the top 10, ITT made the largest plunge—from 8th in 1984 to 42nd in 1994. Three of the 4 other companies that fell out of the top 10 are major defense contractors.
- More pharmaceutical companies are among the largest R&D performers. At least 6 drug companies were among the top 25 in 1994; 10 years earlier, only 1 of those firms was in the top 25.
- Almost all petroleum and chemical companies fell sharply in rank. For example, the largest oil company dropped from 10th to 34th place.
- The "Big Three" automakers are all now in the top 10.
- Many more computer hardware and software companies—some of which did not exist or barely existed in 1984—are now among the leading R&D-performing companies. For example, Microsoft and Apple, ranked 29th and 33rd, respectively, in 1994, were not on the list in 1984, and Intel jumped from 54th to 15th place.

Research and Development Intensity

In addition to absolute levels of and changes in R&D expenditures, another key indication of the health of industrial S&T is R&D intensity. There are a number of ways to measure this indicator, but the one used most frequently is the ratio of R&D funds to net sales. This statistic provides a way to gauge the relative importance of R&D across industries and firms in the same industry.

The ratio of R&D dollars to net sales tends to be fairly stable over time, although year-to-year changes of 0.1 to 0.2 percent are not uncommon. Also, there are substantial differences between industries. (See appendix tables 4-13 and 4-14.)

In 1993, nonfederal R&D spending, as a percent of net sales for all R&D-performing companies classified in manufacturing industries, was 3.1 percent. (See appendix table 4-13.) Although this was a 0.2-percent dip from the preceding year's ratio, the change may be a minor fluctuation and not the beginning of a downward trend. The 1993 ratio is very much in line with that recorded for other recent years; for instance, this ratio has been 3.0 percent or higher since 1985. (See figure 4-8.)

The general stability of the R&D/sales ratio in the 1990s indicates that, despite a lack of growth in manufacturing companies' R&D financing, little change has occurred in the level of importance accorded R&D relative to other discretionary spending. That is, roughly the same proportion of companies' income has been devoted to R&D for almost 10 years.[9]

As mentioned previously, there are significant differences in R&D intensity across industries. (See text table 4-3.) At 12.1 percent, the pharmaceutical industry had the highest, and only double-digit, ratio in 1993. Ten years earlier, it ranked third behind the computer and scientific and mechanical measuring instruments industries.

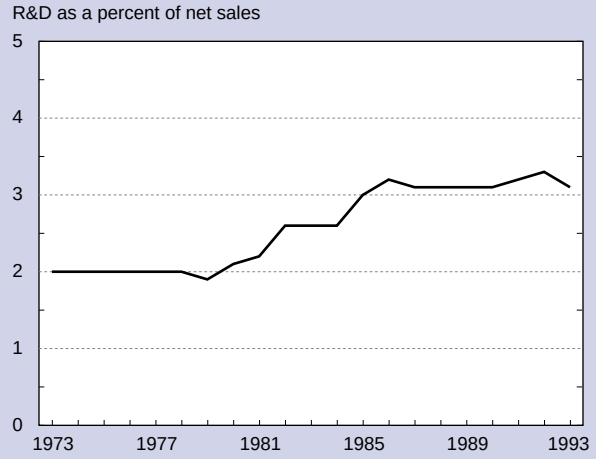
Federal Research and Development Funds

In 1993, industrial firms spent $22.8 billion in Federal funds on R&D. As mentioned earlier in this chapter, Federal R&D support to industry has been declining steadily since 1987. The aircraft and missiles industry is the leading recipient of Federal R&D funds. Interestingly, this industry used to account for more than

[8]The ranking is based on the size of R&D expenses. Included are the amount of funds spent on R&D performed outside the company and the amount spent on R&D performed in other countries. Note that the Compustat data base does not contain privately held companies.

[9]It is important to note that there were significant increases in the overall R&D/net sales ratio between 1981 and 1982 (from 2.2 percent to 2.6 percent) and between 1984 and 1986 (from 2.7 percent to 3.2 percent). Prior to 1982, company R&D funds, as a percent of net sales, had been in the 2.0-percent range for 20 years.

Figure 4-8.
Total nonfederal R&D funding as a percentage of net sales



See appendix table 4-13. *Science & Engineering Indicators – 1996*

Text table 4-3.
Industry segments with the highest and lowest company (and other nonfederal) funds/net sales ratios: 1993

Industry segment	R&D funds/net sales ratio
	Percent
Highest	
Drugs and medicines	12.1
Office, computing, and accounting machines	9.7
Communication equipment	9.3
Scientific and mechanical measuring instruments	8.8
Electronic components	7.9
Optical, surgical, photographic, and other instruments	7.1
Aircraft & missiles	5.2
Lowest	
Petroleum refining and extraction	0.8
Lumber, wood products, and furniture	0.7
Primary metals	0.7
Textiles and apparel	0.5
Food and tobacco products	0.4

SOURCE: Science Resources Studies Division, National Science Foundation, *Research and Development in Industry: 1993* (Arlington, VA: NSF, forthcoming).

See appendix table 4-13.

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two-thirds of all Federal monies spent by companies; the most recent data show this industry accounting for less than one-half in 1993.[10] (See appendix table 4-10.)

There has been a major upsurge in company downsizing, mergers, and restructuring in recent years, particularly among defense contractors. Company executives have had to make some tough choices; for example, they have had to decide whether to stick with the defense business as the mainstay of their operations or branch out into civilian product development. (See *Defense Conversion: Will It Prove Successful?*)

Collaboration Among Firms and with Other Organizations

Cooperative R&D is now an important tool in the development and leveraging of S&T resources. Although data on multifirm and multisector collaborative R&D activities are sparse, there is sufficient evidence to conclude that a major upswing in S&T partnerships has taken place since the early 1980s.[11]

There is also a growing body of literature that helps identify the reasons for the increase in collaborative R&D efforts, their organizational structure, and their economic and political implications. For example, intra-industry collaboration seems to be a response to the same competitive forces affecting all industries: rising R&D costs and risk in pursuing basic research, shortened product life cycles, increasing multidisciplinary complexity of technologies, and intense foreign competition in domestic and global markets. In addition, high-profile, industry-led cooperative research endeavors are more likely than single-firm efforts to attract support from outside sources, such as Government agencies. This section covers several indicators of cooperative R&D activity.

Industrial Research and Development Consortia

The erosion in U.S. firms' technological leadership and the decline in their share of international markets in the 1970s and 1980s have been blamed on many factors (NSB, 1992), including an overly restrictive antitrust environment, which has, in effect, prohibited U.S. companies from collaborating on most activities, including research. Laws originally enacted to preserve domestic competition had become an impediment to U.S. firms' ability to compete in worldwide markets populated by an increasing number of foreign producers and customers. Therefore, restrictions on multifirm cooperative research relationships were lifted with the passage of the National Cooperative Research Act (NCRA) of 1984. This law was designed to encourage U.S. firms to collaborate on generic, precompetitive research. To gain protection from antitrust litigation, firms engaging in a "joint research venture" (JRV)[12] are required by NCRA to register the JRV with the Department of Justice. In 1993, Congress again relaxed restrictions—this time on cooperative production activities—by passing the National Cooperative Research and Production Act, which enables companies to work together in a JRV to apply newly developed technologies.

By the end of 1994, more than 450 JRVs had been registered. The annual number of JRV filings has increased in most years since the law was passed. (See figure 4-9.) Although data on the level of resources invested in these projects are not available, results of two investigations (Link, 1995; Vonortas, 1995) revealed the following:

- The average number of members in a JRV since the passage of NCRA is 13.4.
- The vast majority—83 percent—of U.S. JRV members are profit-making firms; nonprofit groups, including universities and colleges, hold 12 percent of the memberships; and government agencies and organizations hold 5 percent. Registered JRVs with Federal participation include some of the more well-known consortia, such as Semiconductor Manufacturing Technology (SEMATECH) and the Advanced Battery Consortium.

[10]Data from the Aerospace Industries Association (AIA) show a 25-percent decline in sales of military-related hardware between 1990 and 1993 (AIA, 1994).

[11]This section covers only domestic alliances. See International Strategic Technology Alliances in this chapter for information on international collaborative R&D activities.

[12]A JRV is defined as the formation of a new organization jointly controlled by two or more parent institutions whose purpose is to engage in R&D activities. Members can be from different sectors as well as different countries.

Defense Conversion: Will It Prove Successful?*

Declining defense budgets have led to a shrinking U.S. defense industrial base and one that is more dependent on global sales and purchases. Because the U.S. economy is so large, defense downsizing is not having a devastating impact on the Nation as a whole, although certain regions of the country have been adversely affected. Unlike the defense downturns that occurred after World War II and the Korean and Vietnam conflicts, the current situation is not cyclical; that is, because the threat to national security is considerably less than it was during the Cold War, an upturn in defense spending is unlikely to occur anytime in the foreseeable future.

Most large industrial firms that were once heavily dependent on business from the Pentagon have had to make some major adjustments. In general, these defense prime contractors have chosen one of three courses: downsizing, concentrating on the defense business, or conversion.

Most firms have chosen to downsize. For example, companies like McDonnell-Douglas are much smaller than they used to be. The cutback in R&D performed by downsizing firms is reflected in National Science Foundation (NSF) data that show an $8 billion decline in the level of Federal R&D funds spent by industry between 1987 and 1993.

Other companies have chosen to stick with the defense business and are even acquiring divisions and units shed by the downsizing firms. For example, in the early 1990s, Loral and Martin Marietta bought the defense-related businesses of other large defense contractors. The defense business is still profitable, and foreign customers are becoming more numerous. Therefore, those companies that have always been leaders in certain markets will continue to survive and thrive. There will just be fewer of them.

The third group of companies consists of those firms attempting defense conversion, i.e., shifting from military to civilian-related activities. What is meant by the term "defense conversion" is actually diversification. It usually involves finding civilian uses for technologies previously developed for the military. Defense companies diversifying into new markets include Westinghouse, TRW, and Hughes. Although these companies have always had a substantial presence in the civilian sector, they are attempting to find new commercial markets for products and services that were initially developed for military use. Examples of these products include weather satellites and air traffic control systems. In addition, the Government is currently supporting these diversification efforts with programs such as the Technology Reinvestment Project. (See Defense-Related Issues in this chapter.)

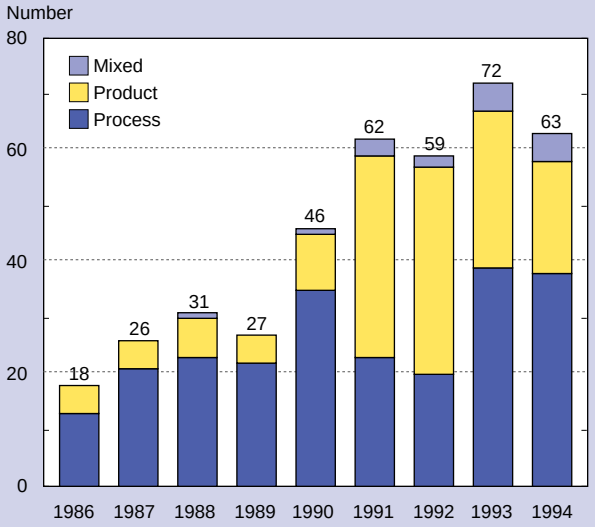
Smaller companies that served as subcontractors on large defense projects are also faced with transition into a peacetime economy. They are finding fewer opportunities because prime contractors are reducing the number of subcontractors and are now competing more often for small projects, business they would not have considered bidding for in the past. Downsizing is not an option for these firms, because they are already small. Diversification is their only choice if they want to survive.

Another group of companies gaining prominence as a result of defense downsizing are spin-off firms. These are companies that got their start using new technologies developed by large companies that did not want to commercialize the new technologies. Examples include a company that took sonar technology developed by a large defense contractor and used it to develop equipment to monitor environmental pollution. Another successful company used encryption technology (developed for the National Security Agency) to make electronic tags to monitor hospital patients. It is too soon to tell how successful overall defense contractors will be diversifying into new markets. The disruption in R&D activities and labor markets caused by the end of Cold War hostilities, however, is likely to be at least somewhat mitigated by the ability of some of these companies to take advantage of burgeoning commercial opportunities.

*Most of the information in this section came from Pages, 1993.

- Most of the research conducted by JRVs has been process-oriented, although there were 2 years—1991 and 1992—during which the number of new filings for product-oriented JRVs exceeded the number of filings claiming process-oriented research.
- Telecommunications and environmental research appear to be the most predominant focus areas for JRVs. The latter is the primary area of research for JRVs formed by companies in the chemicals, petroleum, and transportation equipment industries.
- Few JRVs involve any type of defense-related research or research in fields in which intellectual property rights tend to be well enforced, such as biotechnology, medical equipment, and pharmaceuticals.
- Nearly one-third of the members of JRVs are foreign based. The most well-represented countries are Japan, the United Kingdom, Canada, Germany, and France.

Figure 4-9.
Growth in R&D consortia registered under the National Cooperative Research and Production Act



SOURCE: A.N. Link, *Research Joint Ventures: Patterns for Federal Register Filings* (Interim report, February 1995).

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Federal Cooperative Technology Programs

Federal cooperative technology programs[13] have mushroomed in the past 15 years, a trend reflecting major changes in U.S. S&T policy.[14] That is, the Federal role in supporting S&T programs has been extended beyond the traditional funding of mission-oriented R&D. It now includes support aimed at speeding the development, application, and commercialization of new technologies in areas likely to contribute to economic growth and other societal needs. Factors shaping this new S&T policy include concern about international industrial competitiveness; a desire to maximize the value of Federal investment in S&T; the declining defense budget; and the military's increasing dependence on civilian-led technologies, especially in the area of electronics.

Since 1980, a series of laws have been enacted to promote Federal–civilian partnerships and to facilitate the transfer of technology[15] between sectors. (See text table 4-4 and *SBIR Program Expands Support for Small Business R&D*.) Terms such as partnership and cost shar-

[13]Cooperative technology programs are defined here as public–private initiatives involving Government and industry that sponsor the development and use of technology and improved practices to benefit specific companies. The primary goal is to stimulate economic growth. Excluded are the nonstate or nonagency programs of individual institutions, such as Federal laboratories and universities. Also excluded are programs for which economic benefits are secondary or tertiary goals; for instance, programs that have a main purpose to educate or meet agency mission requirements.

[14]Most of the information in this section was obtained from Coburn, 1995.

[15]Technology transfer can cover a wide spectrum of activities, running the gamut from the exchange of ideas between visiting researchers to contractually structured research collaborations involving the joint use of facilities and equipment.

Text table 4-4.
Principal Federal legislation related to cooperative technology programs

Stevenson-Wydler Technology Innovation Act (1980) Required Federal laboratories to facilitate the transfer of federally owned and originated technology to State and local governments and the private sector. The Act includes a requirement that each Federal lab spend a specified percentage of its research and development budget on transfer activities and that an Office of Research and Technology Application (ORTA) be established to facilitate such transfer.

Bayh-Dole University and Small Business Patent Act (1980) Permitted government grantees and contractors to retain title to federally funded inventions and encouraged universities to license inventions to industry. The Act is designed to foster interactions between academia and the business community. This law provided, in part, for title to inventions made by contractors receiving Federal R&D funds to be vested in the contractor if they are small businesses, universities, or not-for-profit institutions.

Small Business Innovation Development Act (1982) Established the Small Business Innovation Research (SBIR) Program within the major Federal R&D agencies to increase government funding of research with commercialization potential in the small high-technology company sector. Each Federal agency with an R&D budget of $100 million or more is required to set aside a certain percentage of that amount to finance the SBIR effort.

Federal Technology Transfer Act (1986) Amended the Stevenson-Wydler Technology Innovation Act to authorize cooperative research and development agreements (CRADAs) between Federal laboratories and other entitites, including state agencies.

Omnibus Trade and Competitiveness Act (1988) Established the Competitiveness Policy Council to develop recommendations for national strategies and specific policies to enhance industrial competitiveness. The Act created several new programs (e.g., the Manufacturing Technology Centers) in the Department of Commerce's National Institute of Standards and Technology to help small and medium size manufacturers become more competitive.

National Competitiveness Technology Transfer Act (1989) Part of the Department of Defense authorization bill, this act amended the Stevenson-Wydler Act to allow Government-owned, contractor-operated laboratories to enter into cooperative R&D agreements.

Defense Conversion, Reinvestment, and Transition Assistance Act (1992) Initiated the Technology Reinvestment Project (TRP) to establish cooperative, interagency efforts that address the technology development, deployment, and education and training needs within both the commercial and defense communities.

SOURCE: C. Coburn (editor), *Partnerships: A Compendium of State and Federal Cooperative Technology Programs* (Columbus, OH: Battelle Press, 1995).

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SBIR Program Expands Support for Small Business R&D

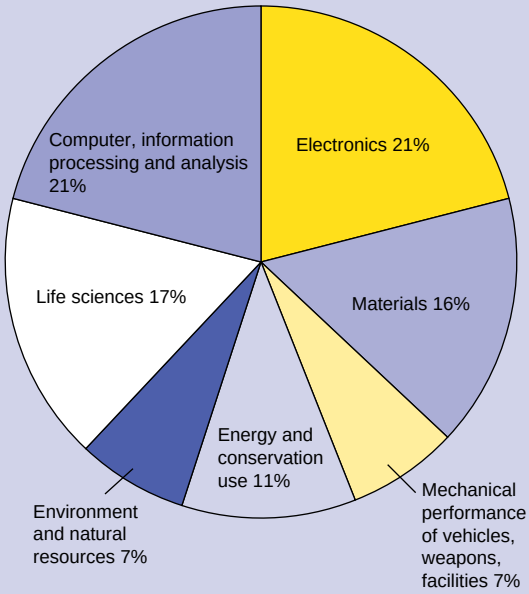
The Small Business Innovation Research (SBIR) Program was created in 1982 to strengthen the role of small firms in federally supported R&D. Since that time, the SBIR Program has directed nearly 29,000 awards worth almost $4 billion in R&D support to thousands of qualified small high-tech companies on a competitive basis. Under this program, which is coordinated by the Small Business Administration (SBA) and is in effect until the year 2000, when an agency's external R&D obligations (that is, those exclusive of in-house R&D performance) exceed $100 million, the agency must set aside a fixed percentage of such obligations for SBIR projects. This percentage initially was set at 1.25 percent, but under the Small Business Research and Development Enhancement Act of 1992, it will rise to 2.5 percent by 1997.

To obtain funding, a company applies for a Phase I SBIR grant: The proposed project must meet an agency's research need and have commercial potential. If approved, grants of up to $100,000 are made to allow the scientific and technical merit and feasibility of an idea to be evaluated. If the concept shows potential, the company can receive a Phase II grant of up to $750,000 to develop the idea further. In Phase III, the innovation must be brought to market with private sector investment and support. No SBIR funds may be used for Phase III activities.

Eleven Federal agencies participated in the SBIR Program in 1993, making awards totaling $698 million, an amount that was equivalent to 1.1 percent of all government R&D obligations. The total obligated for SBIR awards in 1993 was 37 percent more than SBIR obligations in 1992, the largest single-year jump since the program's inception. Whereas 72 percent of the grants awarded were Phase I grants (2,898 of 4,039 awards in 1993), roughly 70 percent of total SBIR funds were disbursed through Phase II grants. Approximately 55 percent of all SBIR obligations were provided by DOD, mirroring this agency's share of the Federal R&D funding total. (See appendix table 4-15.)

SBA classifies SBIR awards into various technology areas. In 1993, the technology areas receiving the largest (value) share of Phase I awards were electronics device performance and computer communications, while optical lasers and biotechnology were the leading technology areas for Phase II awards. In terms of all SBIR awards made during the 1983–93 period, roughly one-fifth were computer-related and one-fifth involved electronics. Each received more than one-half of their support from DOD and National Aeronautics and Space Administration. One-sixth of SBIR awards went to life science research; the bulk of such funding was provided by the Department of Health and Human Services (HHS). Materials-related research, which is funded largely by DOE and NSF, accounted for another one-sixth of total SBIR awards. (See figure 4-10.)

Figure 4-10.
Small Business Innovation Research awards, by technology areas: 1983–93



Small Business Administration, *Small Business Innovation Development Act,* 11th annual report (Washington, DC: 1995).

ing, once rarely heard in government agencies, are now part of the lexicon in most Federal R&D programs. For example, although the dollar amounts are small, the National Science Foundation went from having almost no programs requiring industry cost sharing in 1980 to more than 50 such programs in 1995.

There are now more than 70 Federal cooperative technology programs spread over at least 10 agencies. In fiscal year 1994, Federal agencies spent approximately $2.7 billion on cooperative technology programs. (See text table 4-5.) These cooperative technology programs can be divided into five categories: technology development, industrial problem solving, technology financing, startup assistance, and teaming. The largest of these groups is technology development, with FY 1994 total funding of more than $1 billion. Programs in this group provide assistance to companies to develop or adapt technology and include those that require companies to enter into

Text table 4-5.
Cooperative technology program support

Source of support	Fiscal year 1992	1993	1994
	Millions of dollars		
Federal and state support, total	1,980.0	2,835.1	3,101.5
Federal support, total	1,673.6	2,519.6	2,717.0
Department of Agriculture	429.4	442.2	450.8
Department of Commerce	55.4	88.3	233.4
Department of Defense	692.9	1,257.3	1,101.7
Department of Energy	55.3	71.1	72.0
Department of Health and Human Services	100.3	123.4	133.1
Department of Labor	0.4	1.0	1.6
Department of Transportation	64.3	189.4	349.6
Environmental Protection Agency	19.9	10.4	56.8
National Aeronautics and Space Administration	128.6	191.0	168.6
National Science Foundation	127.1	135.5	149.4
State support, total	306.4	315.5	384.5

SOURCE: C. Coburn (editor), *Partnerships: A Compendium of State and Federal Cooperative Technology Programs* (Columbus, OH: Battelle Press, 1995).

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consortia with other companies, Government agencies, or universities. Examples of these programs are DOD's Manufacturing Technology (MANTECH) program, SEMATECH, the Technology Reinvestment Project (TRP), and NSF's Research Centers programs.

Technology Transfer Activities

Technology transfer activities are now an important mission component of Federal laboratories. (See *The National Laboratories—A New Role?* later in this chapter.) Of course, some agencies, including the Department of Agriculture's (USDA) Agricultural Research Experiment Stations and the National Aeronautics and Space Administration's (NASA) civilian aeronautics programs, have long shared their research with the private sector. According to most available indicators, Federal efforts to facilitate private sector commercialization of Federal technology have made considerable progress since 1987. For instance,

- The number of active cooperative research and development agreements (CRADAs) between Federal laboratories and private industry increased ninefold, rising from 108 in 1987 to almost 975 in 1991. NASA (with 25 percent of the total) and USDA (with 18 percent of the total) accounted for the largest number of CRADAs in 1991; DOE's CRADA total rose from 1 in 1990 to 43 in 1991.
- Federal laboratories increased their number of invention disclosures by 60 percent, and more than doubled their number of patent applications between 1987 and 1991. DOD led all other agencies in these efforts.
- The number of exclusive and nonexclusive licensing agreements between firms and Federal laboratories increased 100 percent. DOE granted the largest number of licenses (351) to industry in the 1987–91 period.

Research and Development Tax Credits

In addition to direct financial R&D support, the Government has tried other policy instruments to stimulate corporate research spending indirectly. The most notable of these efforts has been to offer tax credits on incremental research and experimentation (R&E) expenditures.[16] The credit was first put in place in 1981 and has been renewed six times—most recently, through the end of June 1995.[17] Although the computations are complicated, the tax code provides for a 20-percent credit for the amount of a company's qualified R&D that exceeds a certain threshold.[18] Since 1986, companies have been allowed to claim a similar credit for basic research grants to universities and other qualifying nonprofit institutions, although the otherwise deductible R&E expenditures are reduced by the amount of the basic research credit.[19]

[16]Not all R&D is eligible for such credit, which is limited to expenditures on laboratory or experimental R&D.

[17]For a complete history of the tax credit, measurement of its effectiveness, and comparisons with R&D tax provisions enacted in other countries, see Office of Technology Assessment (1995b).

[18]The complex base structure for calculating qualified R&D spending was put in place by the Omnibus Reconciliation Act of 1989. With various exceptions, a company's qualifying threshold is the product of a fixed-base percentage multiplied by the average amount of the company's gross receipts for the 4 preceding years. The fixed-base percentage is the ratio of R&E expenses to gross receipts for the increasingly distant 1984–88 period. Special provisions cover start-up firms.

[19]In 1992, firms applying for the R&E credit spent about $1 billion on research performed by educational and scientific organizations, of which—after various qualification restrictions—the basic research credit contributed less than $200 million toward the R&E tax credit (OTA, 1995b).

The dollar value of R&E tax credits actually received by firms is unknown. Information from the Internal Revenue Service indicates that in any given tax year this dollar value can be 20 to 30 percent less than the amount for which firms *file* claims—nearly $1.6 billion in 1992, the most recent year for which data are available (OTA, 1995b). This amount has fluctuated since the credit's inception in 1981, but has remained rather steady since 1988. (See figure 4-11 and appendix table 4-16.)

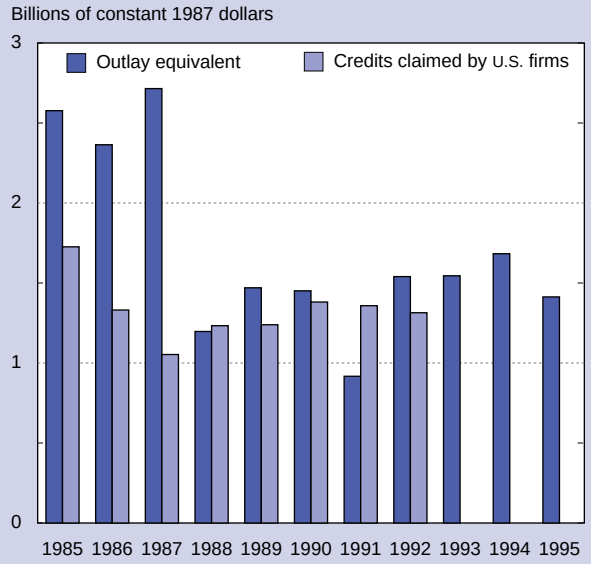
Additionally, as part of the Federal budget process, the U.S. Treasury Department annually calculates estimates of foregone tax revenue (tax expenditures) due to preferential tax provisions, including the R&E tax credit. As one measure of budgetary effect, the Treasury provides outlay-equivalent figures. These allow a comparison of the cost of this tax expenditure with the cost of a direct Federal R&D outlay. Between 1981 and 1994, more than $24 billion was provided to industry through this indirect means of Federal R&D support—an amount equivalent to about 3 percent of direct Federal R&D support. (See appendix table 4-16.)

In general, most of the credit has been claimed by manufacturing firms, which accounted for three-fourths of the $1.6 billion total in 1992. Companies that took the most advantage of the credit were large firms and those that produce pharmaceuticals (17 percent of total), electrical equipment and transportation equipment (14 percent each), and machinery (11 percent). Since 1981, the nonmanufacturing share of claimed credits has risen from less than 20 percent to 24 percent of the total.

The tax credit has received mixed reviews regarding its overall effectiveness. Results of various studies undertaken since the mid-1980s were summarized in a recent literature review and 1995 experts workshop supported by the Office of Technology Assessment (1995b):

- A complete cost-benefit assessment of the R&E tax credit requires information that has not been collected and may be either unavailable or impossible to estimate accurately, and even the most recent studies already are dated. Nonetheless, assessments undertaken soon after initial enactment of the credit (those using data for the years 1981 to 1983) concluded that the R&E tax credit cost more in lost revenues than it produced in additional R&E expenditures. More recent, and somewhat more comprehensive, studies (using data for the years 1988 and later) indicated that the amount of induced R&E spending approximates revenue cost in the short term and exceeds it in the long term[20]; and

Figure 4-11.
R&E tax credits: Government outlays and industry claims



R&E = research and experimentation
NOTE: Internal Revenue Service data on R&E tax credit claims are unavailable for years after 1992.

See appendix table 4-16. *Science & Engineering Indicators – 1996*

- Although some firms substantially rely on the credit—as is often the case in industries with rapidly expanding R&D outlays (as in communications and information technology) and industries for which R&D performance strongly affects market valuation (as in biotechnology)—preliminary evidence indicates that the R&E tax credit rarely factors into individual firms' R&D planning processes.

Federal Research and Development

R&D accounts for only a small portion—roughly 5 percent—of the total Federal budget. Yet trends in Federal R&D support—like overall Federal spending—reflect shifting national priorities. These changes are easily detected by examining the most recent data on Federal R&D obligations. They reflect the Nation's growing emphasis on deficit reduction and a shift in the balance between defense and domestic programs. For example, the level of total Federal R&D obligations in 1995 was actually lower, in real terms, than in 1990. Almost all of this decline is attributable to cutbacks in defense-related programs made possible by the virtual cessation of Cold War hostilities. At the same time, the reduction in defense-related R&D was somewhat counterbalanced by an increase in Federal support for civilian R&D programs, including those aimed at improving diagnosis and treatment of disease, cleaning up the environment, and enhancing technological competitiveness and economic prosperity.

[20]Whatever its ultimate impact on R&D spending, the tax credit has certainly influenced spending less than it could have, had it been less subject to erratic legislative treatment. The tax credit has had to be repeatedly (almost annually) renewed, its calculation provisions have changed considerably over the years, and it was even allowed to lapse several times—circumstances that created considerable uncertainty for businesses that would otherwise have planned to take the tax credit.

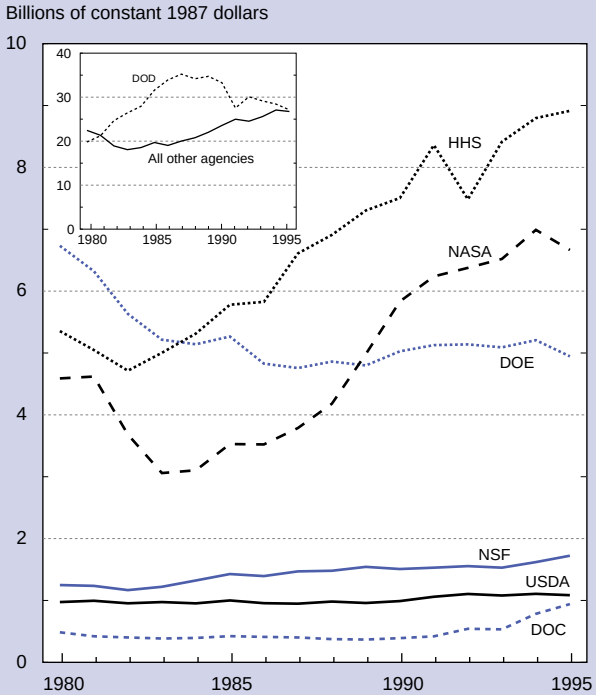
Although Federal R&D financing has traditionally received strong bipartisan support, there are some definite signs that it has become more politicized in recent years. There are clear differences in emphases and priorities. For example, the major political parties are not in tune with each other on the role of the Government in supporting technology development. This disagreement has been brought sharply into focus with the 1994 election of the first Republican Congress in 40 years. The congressional turnover—combined with a Democratic Administration committed to a role for the Federal Government in civilian technology development—has set the stage for this difference of opinion to be thrashed out in the political arena.

It is impossible to know at this time what the final resolution will be. Therefore, the following sections cover recent, not future, trends in Federal R&D obligations.

Patterns of Federal R&D Support

Although 25 Federal departments and agencies fund R&D, 7 account for the vast majority (95 percent) of Government R&D support. (See figure 4-12.) Each of these seven agencies had an R&D budget exceeding $1 billion in FY 1995. In descending order, these agencies are: DOD ($34.9 billion in FY 1995); HHS ($11.5 billion); NASA ($8.6 billion); DOE ($6.4 billion); NSF ($2.2 billion); USDA ($1.4 billion); and the Department of Commerce (DOC) ($1.2 billion). DOC is a recent addition to this list of the largest Federal R&D agencies. (See appendix table 4-17.)

Figure 4-12.
National R&D obligations, by selected agency



DOD = Department of Defense
HHS = Department of Health and Human Services
NASA = National Aeronautics and Space Administration
DOE = Department of Energy
NSF = National Science Foundation
USDA = United States Department of Agriculture
DOC = Department of Commerce

See appendix table 4-17. *Science & Engineering Indicators – 1996*

The decline in total Federal R&D support during the 1990s is almost entirely attributable to cutbacks at DOD. DOD R&D support fell in both current and constant dollars in 5 of the past 6 years. DOD accounted for about half of all Federal R&D obligations in FY 1995, down from nearly two-thirds of the total in 1986, at the height of the Reagan Administration defense buildup. (See figure 4-13.) Defense-related R&D programs financed by DOE were also curtailed during the early 1990s, causing the DOE R&D budget to shrink slightly in real terms during the first half of the decade.

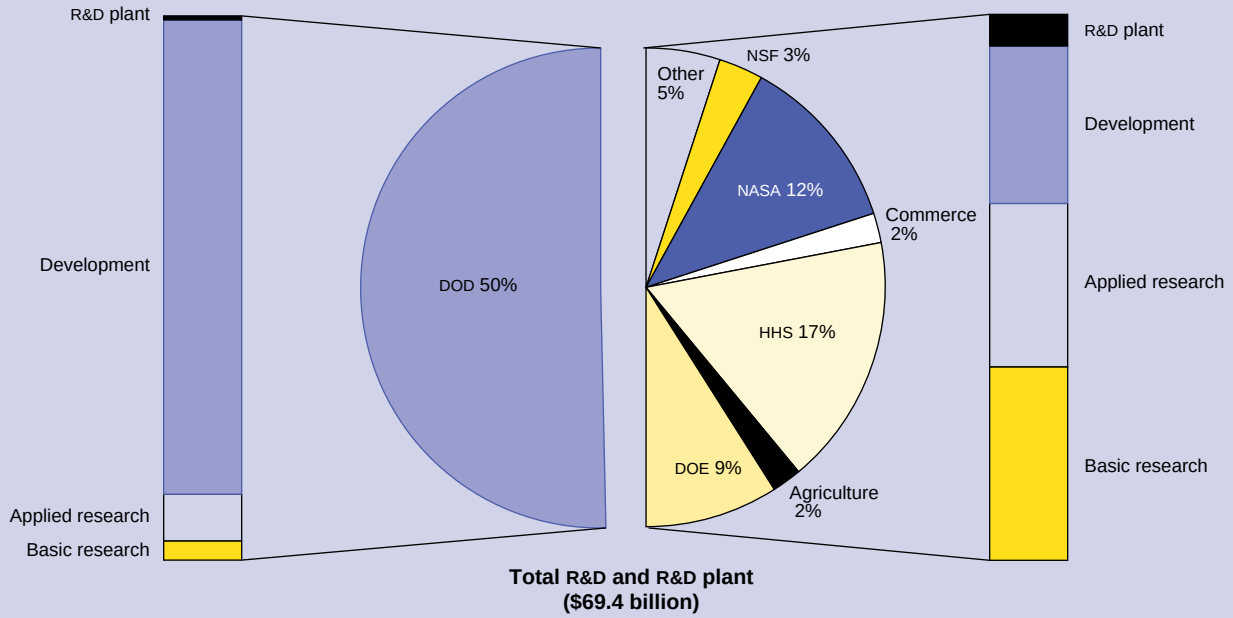
The curtailment of defense-related R&D programs was somewhat counterbalanced by R&D funding gains at other agencies. For example, HHS R&D obligations registered an estimated 3.5-percent average annual real increase between 1990 and 1995. This agency, which is a distant second to DOD in terms of total R&D support, increased its share of the Federal R&D budget from 11 percent in 1986 to 17 percent in 1995. This growth reflects the mission interests of the National Institutes of Health (NIH). NIH accounts for 95 percent of HHS R&D obligations. In addition, two other agencies—NASA and NSF—each had comparable annual average increases of 2.7 percent during the period.

Among all R&D-funding agencies, the Commerce Department experienced the largest percentage increases in R&D support during the late 1980s and early 1990s, although its R&D budget is still relatively small compared with those of the other major R&D agencies. This agency's R&D obligations increased threefold between FY 1988 and 1995. Nearly all of this gain is attributable to the funding of projects awarded under the National Institute of Standards and Technology's (NIST) Advanced Technology Program (ATP), which is currently being re-examined.[21]

Funding of the USDA's R&D programs has been fairly stable in real terms during the 1990s. The National Research Initiative, a merit-reviewed competitive grants program started in FY 1991 to support research in natural resources, the environment, nutrition, and food health and safety, now has a budget exceeding $100 million.

[21]Since 1990, more than $1 billion in public and private funds have been invested in ATP projects. (In addition to the ATP, NIST's Technology Portfolio includes the Manufacturing Extension Partnership, laboratory research and services, and the Baldrige National Quality Program.) Similar to DOD's Technology Reinvestment Project (see section on Defense-Related R&D), ATP was designed to spur the formation of partnerships between industry and the government to develop and exploit high-risk, enabling technologies. Key terms associated with the ATP are *industry-driven* and *cost-shared*; i.e., R&D priorities for the program are established by industry, not the Government, and firms seeking ATP support must provide a portion of, and in the case of multifirm projects, at least half the financing.

Figure 4-13.
Federal obligations, by agency and type of activity: 1995



DOD = Department of Defense
NSF = National Science Foundation
NASA = National Aeronautics and Space Administration
HHS = Department of Health and Human Services
DOE = Department of Energy

See appendix table 4-17.

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Two other agencies with relatively small R&D programs—the Department of Transportation (DOT) and the Environmental Protection Agency (EPA)—experienced sizable gains in R&D obligations in the early 1990s, averaging 11 percent and 5 percent per year, respectively, in real terms between 1990 and 1995. The expansion of R&D programs funded by these agencies reflects the current emphasis on R&D related to environmental protection and transportation advancements in the areas of fuel efficiency and emissions, including the Partnership for a New Generation Vehicle, or "clean car" initiative.

Federal Research and Development Support by Character of Work

Federal obligations for basic research, applied research, and development were an estimated $14.2 billion, $14.0 billion, and $41.2 billion, respectively, in FY 1995. (See appendix table 4-17.) Among these three items in the Federal R&D budget, applied research is estimated to have registered the largest absolute ($3.5 billion) and percentage (34 percent) gains in the first half of the 1990s.

Basic Research

Government funding of basic research has always received strong bipartisan support. Five agencies obligate more than $1 billion annually for basic research; these five agencies also account for 9 out of every 10 Federal dollars spent on basic research. HHS is by far the largest supporter of basic research. This agency's FY 1995 obligations, an estimated $6.2 billion, were more than triple NSF's, which ranks second ($2.0 billion). The other leading supporters of basic research are NASA ($1.8 billion); DOE ($1.7 billion); and DOD ($1.2 billion).

During the 1980s, Federal basic research obligations more than doubled, increasing from $4.7 billion in FY 1980 to $11.3 billion in FY 1990. Basic research support continued to increase during the 1990s, but at a much reduced rate—1.8 percent per year in constant dollars, compared with 4 percent during the previous decade. Among the five leading supporters of basic research, HHS registered the largest absolute and percentage gains, the latter averaging 3.2 percent per year during the 1990s, followed by DOD and NSF, with average annual increases of 2.7 percent and 2.3 percent, respectively. NASA and DOE, which registered the highest growth rates in basic research obligations among the five agencies in the late 1980s, had slight reductions in the 1990s, averaging 1.0 percent and 0.8 percent, respectively.

Applied Research

Federal funding sources for applied research are somewhat less concentrated than those for basic research dollars; i.e., four agencies (NSF drops out of the group) obligate more than $1 billion annually for applied research; those four agencies account for approximately two-thirds of all applied research obligations.

HHS is the leading supporter of applied research, with an estimated $3.1 billion in obligations in FY 1995. (A large portion of these monies support research related to the treatment of various diseases, including cancer and acquired immune deficiency syndrome [AIDS].) DOD is second ($2.7 billion), followed by NASA ($1.7 billion), and DOE ($1.6 billion). HHS recorded a slightly above average increase in applied research obligations in the 1990s, and NASA had a somewhat below average gain. Although both DOD and DOE recorded healthy increases in applied research obligations in the early 1990s, a turnaround is expected in subsequent years. DOD FY 1995 obligations are estimated to be 18 percent lower in real terms than FY 1993 obligations, and DOE's are expected to be down 5 percent between 1992 and 1995.

Development

DOD is the source of approximately three-fourths of all Federal money spent on development. In FY 1995, DOD obligations for development were an estimated $30.7 billion. DOD development obligations have been falling almost continuously in real terms since FY 1989, the year they were at a peak level of nearly $34 billion.

The other Federal agencies that obligate more than $1 billion annually for development are NASA ($3.9 billion in FY 1995); DOE ($2.7 billion); and HHS ($1.6 billion). All of these agencies realized real gains in development obligations between FY 1993 and FY 1995, ranging from about 1 percent for DOE to 12 percent for HHS. The DOE gain partially offset a decline that the agency suffered between 1990 and 1992.

Research and Development Agency-Performer Patterns

Most Federal R&D funds are actually spent in other sectors of the economy. R&D funding relationships between supporting agencies and performing sectors are well established and tend to be fairly stable over time. (See appendix tables 4-18 and 4-19 and text table 4-6.) For example,

- DOD is the source of nearly 80 percent of the Federal R&D money spent by industry. More than 90 percent of those funds support development work. Two other agencies—NASA and DOE—provide most of the other Federal R&D dollars industry receives.
- HHS is the largest supporter of federally financed R&D performed at universities and colleges, accounting for more than one-half of all Federal R&D funds received by these institutions. In fact, most of HHS's R&D obligations support work performed in academia; only one-fifth are spent internally, mostly in NIH laboratories. HHS is also the largest supplier of Federal R&D funding for nonprofit organizations. Approximately 5 percent of HHS obligations are slated for industrial firms.
- The other leading supporters of R&D conducted in academic laboratories are NSF and DOD. Approximately 90 percent of the NSF research budget supports projects at universities and colleges; 10 percent is used to fund work at FFRDCs administered by NSF and DOD.
- DOE and DOD supply the majority of Federal R&D obligations for FFRDCs. More than one-half the DOE R&D budget is spent at FFRDCs.
- Unlike all other Federal agencies, three departments—Agriculture, Commerce, and Interior—spend most of their R&D obligations internally. Most of the R&D supported by these agencies is mission-oriented and conducted in laboratories run by the Agricultural Research Service, NIST, and the Geological Survey. (See appendix table 4-20.)

Most Federal basic research dollars are spent at universities and colleges; this sector receives most of its basic research support from HHS (52 percent in FY 1995) and NSF (22 percent). Federal obligations for basic research conducted by private firms are concentrated in the research budgets of NASA (43 percent), HHS (23 percent), and DOD (14 percent). Federal in-house work on basic research programs is distributed among several agencies, with the largest portions conducted by HHS (37 percent), NASA (18 percent), and USDA (16 percent).

Fields of Science and Engineering Research

Among fields receiving Federal research support, life sciences garner the largest share of both basic and applied research obligations. (See appendix table 4-21.)

An estimated $6.9 billion was obligated for basic research in the life sciences (which includes the biological, medical, and agricultural subfields) in FY 1995, nearly half the basic research total of $14.2 billion. This support has grown steadily since the early 1980s, although the rate of increase slowed considerably during the mid-1990s, consistent with the growth pattern for all of HHS, the major funding agency for life sciences. (See figure 4-14 and appendix tables 4-22 and 4-23.)

DOE provides most of the funding for basic research in the physical sciences, which accounted for an estimated 20 percent of all basic research obligations in 1995. Support for research in this field has been falling since 1991. Almost all of the decrease occurred in the physics subfield, where funding for the Superconducting Super Collider was eliminated in an effort to reduce the Federal deficit.

Life sciences received the largest applied research funding support—an estimated $4.7 billion in FY 1995, 34

Text table 4-6.
Estimated Federal R&D obligations, by character of work, performer and primary funding source: FY 1995

Character of work and performer	Performer, total Federal obligations	Primary funding source		Secondary funding source	
	Millions of dollars	Percent		Percent	
R&D, total	69,366	DOD	50	HHS	17
Federal intramural laboratories	16,724	DOD	49	NASA	15
Industrial firms	31,244	DOD	77	NASA	13
Industry-administered FFRDCs	1,298	DOE	81	DOD	13
Universities and colleges	12,097	HHS	54	NSF	15
University-administered FFRDCs	3,608	DOE	54	NASA	30
Other nonprofit insitutions	2,712	HHS	63	NASA	11
Nonprofit-administered FFRDCs	890	DOD	55	DOE	39
Basic research, total	14,201	HHS	44	NSF	14
Federal intramural laboratories	2,720	HHS	37	NASA	18
Industrial firms	964	NASA	43	HHS	23
Industry-administered FFRDCs	213	DOE	77	HHS	23
Universities and colleges	7,497	HHS	52	NSF	22
University-administered FFRDCs	1,422	DOE	64	NASA	21
Other nonprofit insitutions	1,130	HHS	79	NSF	10
Nonprofit-administered FFRDCs	88	DOE	84	HHS	8
Applied research, total	13,960	HHS	28	DOD	22
Federal intramural laboratories	4,880	DOD	21	HHS	20
Industrial firms	3,165	DOD	46	NASA	24
Industry-administered FFRDCs	422	DOE	81	HHS	9
Universities and colleges	3,343	HHS	59	DOD	11
University-administered FFRDCs	804	DOE	72	NASA	13
Other nonprofit insitutions	916	HHS	63	AID	14
Nonprofit-administered FFRDCs	131	DOE	76	HHS	8
Development, total	41,205	DOD	74	NASA	12
Federal intramural laboratories	9,124	DOD	75	NASA	13
Industrial firms	27,114	DOD	83	NASA	10
Industry-administered FFRDCs	663	DOE	82	DOD	11
Universities and co lleges	1,257	HHS	52	DOD	29
University-administered FFRDCs	1,381	NASA	49	DOE	34
Other nonprofit insitutions	666	HHS	35	NASA	26
Nonprofit-administered FFRDCs	671	DOD	72	DOE	26

AID = Agency for International Development
DOD = Department of Defense
DOE = Department of Energy
FFRDC = federally funded research and development center
HHS = Department of Health and Human Services
NASA = National Aeronautics and Space Administration
NSF = National Science Foundation

See appendix table 4-18.

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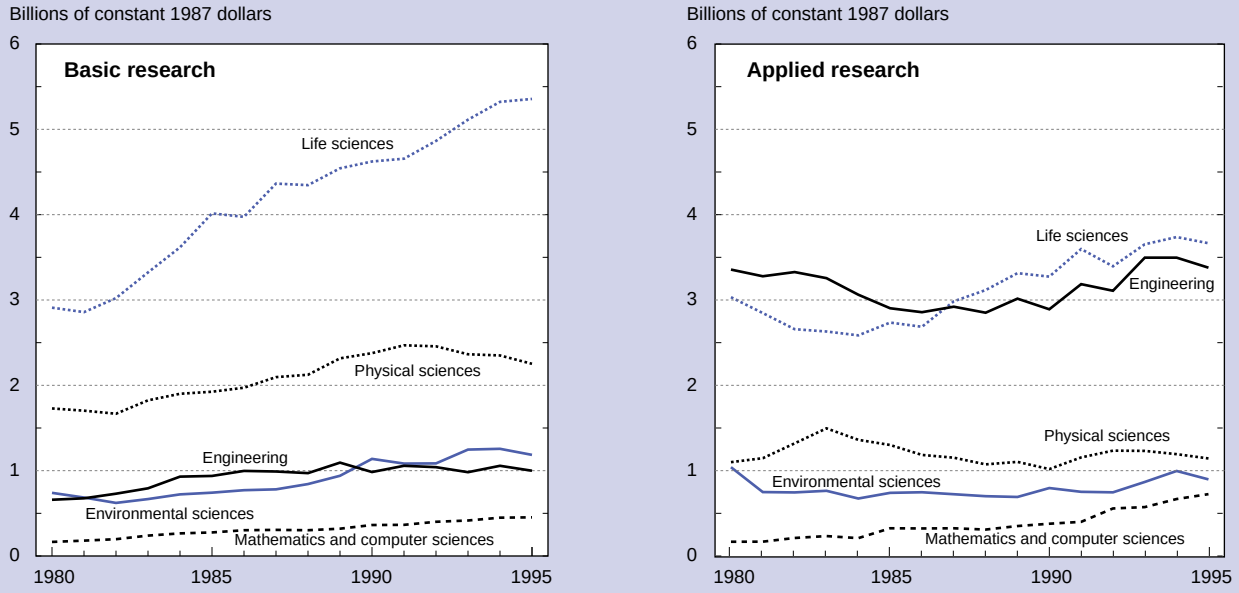
percent of the total. Engineering was close behind with $4.3 billion in obligations, 31 percent of the total. All fields—except the social sciences—registered real gains between FY 1990 and FY 1993; mathematics and computer sciences outpaced the others, with an average annual increase of 14.4 percent. Gains in the other fields ranged from 6.5 percent in the physical sciences and engineering to 2.9 percent in the environmental sciences during that period. Between FY 1993 and FY 1995, however, all fields except the mathematical and computer sciences are expected to have rates of change below or close to zero. (See appendix table 4-23.)

Cross-Cutting Research and Development Initiatives

The current Administration, through its National Science and Technology Council, has articulated the following goals for U.S. S&T programs (Clinton and Gore, 1994):

- Maintain leadership across the frontiers of scientific knowledge;
- Enhance connections between fundamental research and national goals;
- Stimulate partnerships that promote investments in fundamental science and engineering and effective use of physical, human, and financial resources;

Figure 4-14.
Federal obligations for research, by field



See appendix tables 4-22 and 4-23.

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- Produce the finest scientists and engineers for the 21st century; and
- Raise scientific and technological literacy of all Americans.

These goals currently serve as guideposts for setting S&T priorities, along with additional policy directives that emphasize the importance of peer review, cost-shared partnerships, human resources development, international cooperation, and environmental objectives in awarding funding for S&T programs.

The previous Administration adopted—and the current Administration has continued to use—a new approach to planning, budgeting, and coordinating Federal support for S&T. In the President's annual budget, several S&T programs are singled out for special attention because they (1) have been deemed vitally important to the country's future growth and prosperity and (2) involve multiagency and multidiscipline collaboration and support; hence, they are usually referred to as cross-cutting initiatives. Each of these cost-sharing partnerships involves not only the participation and financial support of several Federal agencies, but also private sector participation.

In its most recent budget proposal, the Clinton Administration included funding that amounted to a total of $7.8 billion for six cross-cutting initiatives:

- Technology and Learning Challenge,
- Partnership for a New Generation of Vehicles,
- Construction and Building,
- Physical Infrastructure for Transportation,
- Environment and Natural Resources, and
- High Performance Computing and Communications.

The largest of these initiatives in terms of the dollar support is the Environment and Natural Resources program (this program is primarily, but not exclusively, for R&D). Twelve agencies are expected to contribute a total of $5.3 billion in FY 1996; $2.2 billion of those funds will support the U.S. Global Change Research Program.

The other initiative with a proposed budget exceeding $1 billion is the High Performance Computing and Communications program, which has nine agency participants. Its purpose is to secure U.S. leadership in information and communications technologies and to support the National Information Infrastructure initiative.

Congress is deliberating on the appropriate funding levels and priorities for these initiatives. Priority is being placed on basic research as opposed to technology programs.

Federally Funded Research and Development Centers

Federal R&D obligations for all government laboratories are expected to equal $22.5 billion in FY 1995, 37 percent of total Federal R&D obligations. (See text table 4-7.)

Thirty-nine of these laboratories are designated FFRDCs.[22] R&D obligations for these facilities totaled $5.8 billion in FY 1995. (See appendix tables 4-3 and 4-24.)

[22]FFRDCs include both Government-owned, contractor-operated labs and labs that are owned by nongovernment organizations but do virtually all of their work for the Government.

Text table 4-7.
Estimated Federal R&D obligations, by selected agency and government laboratory: FY 1995

Agency	Total R&D	Total laboratory	Intramural	FFRDCs
	Millions of dollars			
All agencies, total	69,366	22,520	16,724	5,796
Department of Agriculture	1,397	945	945	*
Agricultural Research Service	672	640	640	0
Forest Service	213	187	187	0
Department of Commerce	1,212	662	662	1
National Institute of Standards and Technology	694	234	234	*
National Oceanic and Atmospheric Administration	508	418	417	1
Department of Defense	34,927	9,049	8,160	889
Department of Energy	6,370	4,030	678	3,353
Department of Health & Human Services	11,481	2,498	2,268	230
National Institutes of Health	10,851	2,160	1,930	230
Department of the Interior	631	559	559	*
U.S. Geological Survey	359	334	334	0
National Aeronautics and Space Administration	8,585	3,555	2,481	1,075

* = less than $500,000
NOTE: These figures reflect funding levels as reported by Federal agencies in March through October 1994.

SOURCE: Science Resources Studies Division, National Science Foundation, *Selected Data on Federal Funds for Research and Development, Fiscal Years 1993, 1994, and 1995,* NSF 95-334 (Arlington, VA: NSF, 1995).

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FFRDCs are R&D-performing organizations administered by industrial firms, universities, or nonprofit organizations and financed either exclusively or substantially by a Federal agency either to meet particular R&D objectives or to provide major facilities at universities for research and related training purposes. There are four categories of FFRDCs: research laboratories, R&D laboratories, study and analysis centers, and systems engineering/systems integration centers.

The most well-known FFRDCs are often referred to as the national laboratories. These 10 facilities are administered by DOE. Three were established during World War II specifically to design and build nuclear weapons; six others were created in the decades immediately following the war to develop commercial applications of nuclear technology.[23] (See *The National Laboratories—A New Role?*)

Research and Development Support by Agency

Despite an increase in collaborative efforts with the outside world, most of the work conducted at FFRDCs is still defense-related R&D funded by DOE. This agency provided an estimated $3.4 billion in FY 1995, more than half the FFRDC total. (See appendix table 4-25.) DOE is the sponsoring agency for 19 FFRDCs, including the 10 national laboratories.[24] Eleven of these facilities are administered by universities and colleges, five by industrial firms, and three by nonprofit organizations. DOE funding of work performed at FFRDCs reached an all-time high of nearly $4 billion in FY 1992. Recent declines are largely attributable to the removal of three industry-administered laboratories (Bettis Atomic Power Labora-

[23]The 10 laboratories are Lawrence Berkeley, Los Alamos, and Oak Ridge, which were established during World War II to design and build nuclear weapons; Argonne, Brookhaven, Sandia, Idaho Engineering, Lawrence Livermore, and Pacific Northwest, which were created between 1946 and 1965 to advance civilian uses of nuclear technology; and the National Renewable Energy Laboratory, which was established to conduct R&D on alternative energy sources. The National Renewable Energy Laboratory was given FFRDC status in 1991.

[24]In 1994, the Secretary of Energy established an independent panel, officially named the Task Force on Alternative Futures for the Department of Energy National Laboratories. The panel was charged with advising the department on the (1) future role of the national labs, now that the United States is no longer making bombs the way it used to and (2) management of the labs. The panel's conclusions were issued in a publication known as *The Galvin Report* (after the panel chairman, retired Motorola Chief Executive Robert Galvin). It advised the department

- Not to dismantle the national laboratory system (although it allowed that some downsizing is probably in order, given the labs' reduced mission responsibilities in the post-Cold War era);
- Not to transform the labs' core missions and competencies; i.e., the panel recommended that the labs (1) focus on what they do best, which is long-term, fundamental research, (2) limit their technology transfer activities to those involving the dissemination of research results; and (3) not expand their R&D activities to include technologies that would mainly benefit private sector companies.
- To revamp the way the laboratories are managed. The panel leveled its harshest criticism at DOE and Congress. The panel members concluded that too much bureaucracy and oversight have hampered the labs' operation and productivity and distorted their missions. The panel recommended that each lab adopt a corporate style of management.

Other reports on Federal laboratories have been produced in recent years, including DOD's Dorman Report (Department of Defense, 1995c), NASA's Foster Report (NASA, 1995), and HHS' Bishop/Calabresi Report (National Institutes of Health, 1995) and Cassell/Marks Report (NIH, 1994).

The National Laboratories—A New Role?

The role of the 10 national laboratories in the Nation's S&T enterprise has been the subject of an ongoing dialogue on their future, with respect to their R&D programs becoming more commercially relevant. Like the rest of the defense community, these laboratories are facing the challenge of finding alternative activities in light of continuing reductions in military expenditures. In addition, not only are no new nuclear weapons now planned, but also interest in expanding civilian nuclear energy capabilities has been on the decline because accidents like those at Three Mile Island and Chernobyl and the problem of nuclear waste cleanup and disposal have made future investment in nuclear technology problematic.

Increasingly, the national laboratories have begun to redefine their missions by changing the focus of their research activities to include participation in S&T projects likely to provide commercial benefits to the private sector. Recent laws have made technology transfer an official mission of the laboratories. (See text table 4-4.) Evidence of the impact of these laws is found in the growing number of CRADAs. (See Technology Transfer Activities in this chapter.)

In 1994, Congress asked the General Accounting Office (GAO) to conduct a study of the 10 national laboratories to assess their potential for commercial product development.

> Since 1980, the Congress has had an active interest, expressed in a series of laws, in seeing that more of the national laboratories' outputs be put to commercial uses. Changing needs for defense technology resulting from the end of the Cold War and concern with maintaining U.S. industry's competitiveness in global markets have led several members of Congress to open a public debate and propose new legislation that addresses the national laboratories' missions, structure, and cooperation with industry. Among the alternatives being considered in the public debate are reducing all the laboratories' budgets,* consolidating or closing some of them, and redirecting their weapons development mission toward commercial product-related R&D in such areas as technology development for environmental restoration, energy, and high-performance computing (GAO, 1994).

After reviewing data for FY 1992 and earlier years and interviewing laboratory officials, the GAO investigators concluded the following:

- Less than half (44.6 percent) of the laboratories' efforts were spent on basic and applied research;
- Slightly more than half (52.4 percent) of their R&D- and S&T-related funds financed research related to commercial product development during FY 1992. More specifically, 30.9 percent of the laboratories' total efforts were spent on development projects, 14.4 percent on providing technical assistance, and 7 percent on technology transfer;
- Most of the work classified as development (56.7 percent) was devoted to defense activities (which may have more limited market opportunities), as opposed to nondefense activities; and
- The work of the laboratories had the potential to contribute to the development of commercially viable technologies. This conclusion was based on three indicators: (1) the formation of cooperative R&D agreements between the laboratories and industry increased from 17 in FY 1989 to 196 in FY 1992. (See the section on Federal Cooperative Technology Programs)†; (2) about three-fourths of the 10 laboratories' R&D expenditures were focused on those technologies deemed vital to national needs by the National Critical Technologies Panel (OSTP, 1995a); and (3) over half of the managers of programs with commercial product potential expected clear evidence of that potential to emerge within 5 years or less (from FY 1992) (GAO, 1994).
- Although the GAO staff concluded that the potential for commercial product development exists, they cautioned that whether or not the laboratories will actually achieve commercial applications for their work is unknown because any potential products are still several years away from market entry.

Although it is still too early to document Federal laboratories' contribution to product development, there is clear evidence of growing cooperation between FFRDC researchers and researchers in other sectors. Coauthorship patterns of articles published in a set of about 4,000 scientific and technical journals# show that, between 1981 and 1993, industry, universities, FFRDCs, and Federal agencies each experienced a steady increase in the number and percentage of publications with authors outside their own research community.

The growth in multi-institutionally authored papers was particularly notable for researchers employed at FFRDCs. In 1981, 39 percent of scientific and technical papers published by FFRDC researchers were authored with researchers in other sectors; in 1993, the share of FFRDC papers published with non-FFRDC co-authors had risen to 57 percent. Similarly, 58 percent of papers by researchers in Government agencies in 1993 had co-authors from other sectors (including FFRDCs), compared with 49 percent in 1981.

A recent study covering 1981–91 (Stevens, Kroll, and Narin, 1994) shows that, generally, the share of multi-institutionally authored papers grew for each individual Federal agency during this 10-year period, with the greatest growth (in both absolute numbers and as a percentage of publications) reported for NIH- and NASA-based researchers, and for several of DOE's FFRDCs (notably Lawrence Livermore, Sandia, Oak Ridge, and Argonne).

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*The DOE Secretary has proposed trimming $10.6 billion from the agency's budget over the next 5 years.

†More recent data show that the three weapons labs (Los Alamos, Sandia, and Livermore) have now signed more than 300 CRADAs with industry to conduct cost-shared collaborative research.

#See Chapter 5, Academic Research and Development: Infrastructure and Performance for a discussion of relative strengths and shortcomings of bibliometric data and additional analysis of intersectoral publication matters. Data presented here are drawn from appendix table 5-37.

tory, Hanford Engineering Development Lab, and Knolls Atomic Power Laboratory) from FFRDC designation in late 1992.

NASA ranks second in terms of R&D funds spent at FFRDCs; FY 1995 R&D obligations amounted to $1.1 billion, a large gain over the FY 1993 and FY 1994 levels of $685 million and $816 million, respectively. NASA is the only major FFRDC-supporting agency expected to have an increase between 1992 and 1995. The agency sponsors only one FFRDC, the Jet Propulsion Laboratory (administered by the California Institute of Technology).

DOD sponsored 10 FFRDCs in 1995: 2 administered by universities and 8 by nonprofit organizations. Total DOD support is estimated to have fallen 42 percent in the mid-1990s—from $1.5 billion in FY 1992 to $889 million in FY 1995. More than half the decrease occurred in university-administered facilities. Industry-administered FFRDCs appear to have "lost" $250 million in DOD funding in the mid-1990s; the dollar decline is primarily attributable to the removal of FFRDC designation from the three laboratories mentioned above.

Research and Development Support by Type of Administering Organization

FFRDCs Administered by Academic Institutions

Universities and university consortia administered 19 FFRDCs in 1995. (See appendix table 4-26.) R&D obligations for these facilities totaled an estimated $3.6 billion in that year, with $2.0 billion provided by DOE, $1.1 billion by NASA, $300 million by DOD, and $260 million from all other Federal agencies.

Although the level of R&D funding has been relatively stable (in current dollars) during this decade, it should be noted that a 50-percent reduction in DOD funding was counterbalanced by an increase in support from NASA.

Three university-administered FFRDCs have annual R&D funding levels exceeding $500 million. In 1993 (the most recent year for which data are available), the Jet Propulsion Laboratory had R&D obligations equaling $742 million. This facility serves as NASA's principal center for solar system exploration. The other two—Lawrence Livermore and Los Alamos—are national laboratories, both administered by the University of California. In FY 1993, they had R&D obligations of $705 million and $637 million, respectively. More than 80 percent of their R&D funding comes from DOE; DOD supplies about 15 percent. While R&D funding at Los Alamos has been relatively stable, support of projects undertaken at Livermore fluctuated considerably during the 1990s. Three university-administered FFRDCs—Lincoln Laboratory, Argonne National Laboratory, and Brookhaven National Laboratory—had R&D obligations in the $200-million to $300-million range in FY 1993.

NSF sponsors four university-administered FFRDCs. The largest of these is the National Center for Atmospheric Research (with FY 1993 R&D obligations of $56 million). The other three, with combined FY 1993 obligations of $65 million, are astronomy observatories.[25]

FFRDCs Administered by Industrial Firms

With the removal of FFRDC designation from three laboratories in the early 1990s, the number of industry-administered FFRDCs is down to six. DOE provided all but $300 million of an estimated $1.3 billion received by these facilities in 1995.

Five of the six industry-administered FFRDCs are sponsored by DOE. The largest of these—and the largest of all FFRDCs in terms of 1993 R&D obligations—is Sandia National Laboratory. In FY 1993, it received an estimated $880 million in R&D obligations (DOD provided about 20 percent of the total). The second largest industry-administered FFRDC is Oak Ridge National Laboratory with FY 1993 R&D obligations of $320 million. Both facilities are administered by subsidiaries of Lockheed Martin, and both registered 10-percent increases in R&D funding between 1992 and 1993. Although Sandia also had sizable funding gains between 1989 and 1992, Oak Ridge recorded a fairly substantial decline between 1990 and 1992.

Two industry-administered FFRDCs had their R&D activities cut by more than half between 1990 and 1993. The Idaho National Engineering Laboratory and the Savannah River Technology Center now spend less than $100 thousand annually on R&D. Before it was removed from FFRDC designation, Hanford also experienced a sharp decline in its R&D activity. All of these cuts reflect the fact that, for the first time in half a century, the United States is no longer manufacturing nuclear warheads. For example, no new plutonium has been generated at Savannah River since 1988.

HHS sponsors one FFRDC. The National Cancer Institute (NCI) Frederick Cancer Research and Development Center is administered by four different companies. This facility had just over $100 thousand in R&D obligations in 1993.

FFRDCs Administered by Nonprofit Organizations

The 15 FFRDCs administered by nonprofit organizations had an estimated total of $890 million in R&D obligations in FY 1995. Most of this support—nearly $500 million—was provided by DOD, which sponsors eight of these facilities. DOE contributed an estimated $350 million, and all other agencies contributed a little over $50 million.

Most of the nonprofit-administered FFRDCs are much smaller than those operated by academic institutions and industrial firms. The two largest in terms of FY 1993 obligations were the C3I (Command, Control, Communication, and Intelligence) Center (administered by the MITRE Corporation) and the Aerospace Corporation, with

[25]The National Radio Astronomy Observatory, the National Optical Astronomy Observatories, and the National Astronomy and Ionosphere Center

R&D obligations amounting to $188 million and $150 million, respectively. Both of these FFRDCs provide systems engineering and other technical support to DOD.

Six of the nonprofit-administered facilities were given FFRDC designation in the late 1980s or early 1990s. The sponsoring agencies for two of these laboratories—the Federal Aviation Administration and the Internal Revenue Service—are new to the FFRDC business.

Geographic Distribution of Research and Development Spending

The economy has undergone major structural changes since the decades immediately following World War II, when an abundant supply of high-wage, low-skill manufacturing jobs was the backbone of U.S. prosperity. For example, the diminishing number of well-compensated employment opportunities for individuals who lack post-secondary education or technical skills has been widely reported and documented and has captured the attention of policymakers and politicians at all levels of government. All-out efforts have been launched on several fronts to ease the transition from an economy largely dependent on workers' physical contributions to one that will rely increasingly on their mental strengths and capabilities.

State-level officials have been at the forefront in the quest for long-term solutions to the serious problems associated with blue-collar worker displacement. Economic revitalization is at the top of their agendas, and they have undertaken an array of strategies designed to fill the void left by declining traditional manufacturing and agricultural industries that were once the major sources of livelihood for their states' residents. A popular, nearly universal approach has been to implement a number of programs and policies—many aimed at strengthening their states' research and education infrastructure—as inducements to high-technology businesses to locate in their jurisdictions. Recently compiled information on state-level initiatives shows a major boost in these activities in recent years. Before reviewing these data, it is important to examine the geographic distribution of U.S. R&D investment—including levels of spending by state and the research intensity of state economies—from a national perspective. Absolute levels of R&D performance are indicators not only of a state's current capacity to support S&T-based economic development but also, to a certain extent, of a state's near-term potential to build on its S&T base.

Leading States and Sector Performance Patterns

R&D is substantially concentrated in a small number of states, a solidly entrenched configuration created by past public and private sector choices that were influenced by multiple economic and scientific considerations. Therefore, this historic pattern of concentration is unlikely to change in the foreseeable future. (See figure 4-15.)

One-half of the $166 billion spent on R&D in the United States in 1993 was expended in six states—California, New York, Michigan, Massachusetts, New Jersey, and Pennsylvania. Add four more states—Maryland, Texas, Illinois, and Ohio—and the proportion jumps to two-thirds of the national total. In California alone, $34 billion, or one-fifth of all U.S. R&D funds, were spent. In each of the other nine leading states, R&D spending ranged between $6 billion and $11 billion. (See text table 4-8 and appendix table 4-27.) In contrast, the smallest 30 states collectively accounted for about $23 billion, or less than 15 percent of the R&D conducted nationwide in 1993.

In addition to geographic concentration, there is a high degree of stability among state rankings. For example, the 10 states with the highest R&D performance totals in 1993 were also at the top of the list in 1975. There have been changes in some of the rankings, but these tend to be minor and mainly among those ranked below the top five. For example, between 1989 and 1993, the order of the five leading states stayed the same, but Maryland rose from 10th to 7th and Texas fell from 6th to 8th.

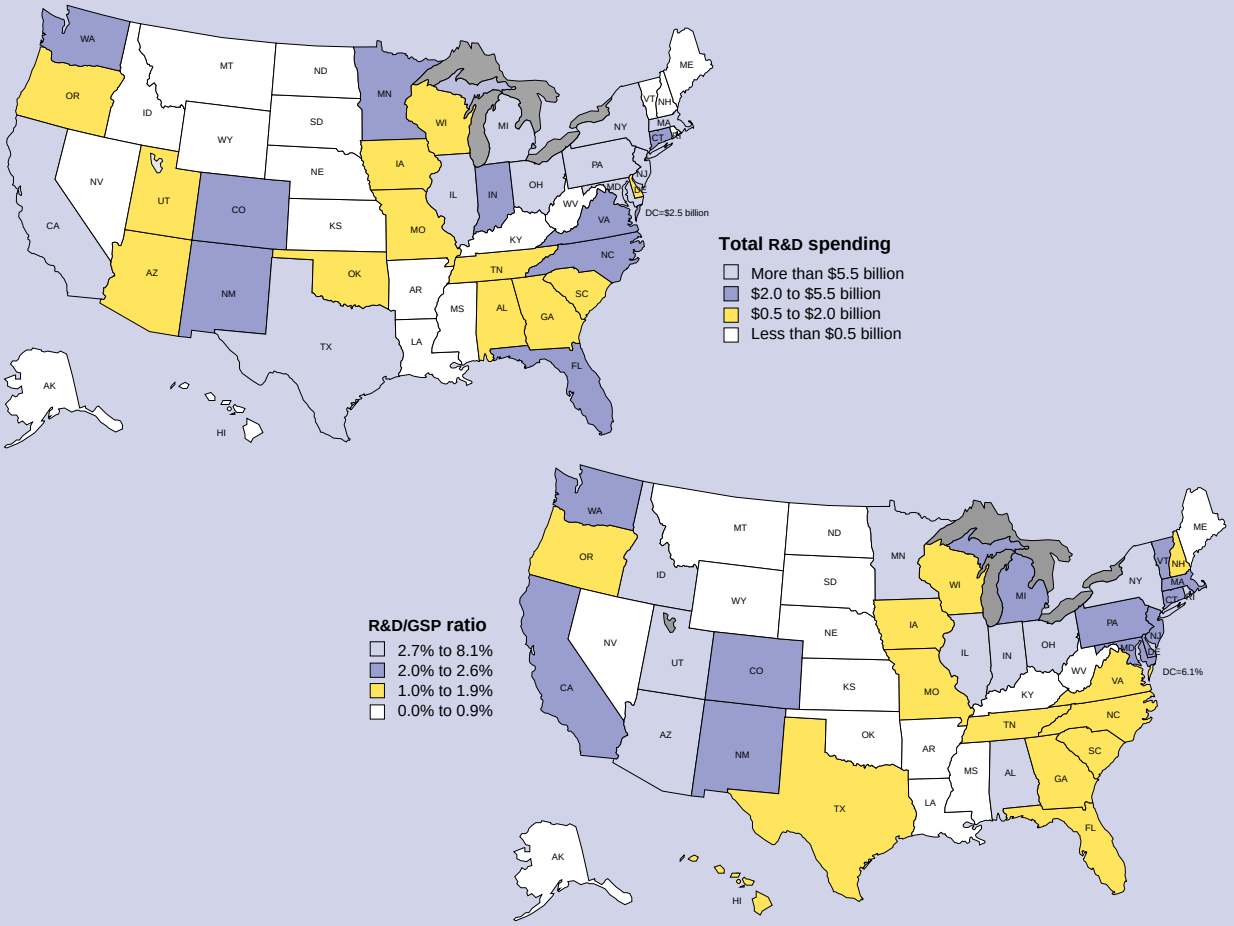
Not coincidentally, states that are national leaders in total R&D performance also usually rank among the leading sites in industrial and academic R&D performance. (See appendix table 4-27.) Of the 10 states that lead in total R&D,

- All but Maryland ranked among the top 10 in industrial R&D performance—Washington (11th for total R&D) held the 10th slot; and
- All but New Jersey ranked among the top 10 in academic R&D performance—North Carolina (18th for total R&D) is on the list instead.

There is somewhat more variation in the distribution of Federal R&D performance. Although California ranks second, the other top spots were held by Maryland, the District of Columbia, and Virginia, ranking first, third, and fourth, respectively, in 1993. These positions reflect the concentration of Federal research facilities, such as NIH, in the Washington, D.C., metropolitan area. Alabama and Florida had the fifth and sixth-highest levels of Federal R&D expenditures in 1993. Undoubtedly, their strong showing in this category is attributable to the sizable presence of the space-related R&D programs conducted in those states.

Among the top 10 states, California had the largest absolute increase in total R&D spending between 1989 and 1993—$2.8 billion. This increase occurred despite a $5.4 billion decline in Federal R&D support to firms that perform R&D in California, a major source of worker displacement in that state. The decline in Federal R&D support was more than offset by gains in the private sector. During this period, California firms' R&D spending of their own funds rose by more than $8 billion. Much of this increase probably occurred in Northern California, which is famous for its Silicon Valley and for leading the

Figure 4-15.
R&D expenditures, by in-state performance: 1993



See appendix tables 4-27 and 4-28.

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Nation in biotechnology research.

Similar to California, Texas—which experienced the smallest percentage and absolute increases in R&D spending between 1989 and 1993—had a sizable decline ($1.2 billion) in Federal R&D support between 1989 and 1993. Unlike California, however, the increased industrial R&D investment in this state was not large enough to offset the decline.

Maryland had the highest percentage increase—46 percent—in R&D dollars spent within its borders between 1989 and 1993. The gain was equally distributed between Federal and industrial performers—each rose about $1 billion dollars. One of the major factors driving this increase was the biotechnology industry. Proximity to NIH and other medical research facilities is a lure for many companies in this industry.

There is also stability among the states ranked 11th through 20th. Between 1989 and 1993, only one state was dropped and one state was added to the list. Missouri, which was ranked 14th in 1989, fell to 23rd in 1993, and Colorado moved up from 21st to 15th. Other changes involved Virginia (which rose from 16th to 13th) and Minnesota (from 17th to 14th). Among the states ranked 11th through 20th, Washington had the largest absolute increase and Colorado, the largest percentage increase, in the 1990s.

Text table 4-8.
Share of U.S. R&D, by state in which the R&D is performed

State	1975	1985	1993
	Percent		
California	18.6	20.7	20.3
New York	8.1	7.8	6.6
Michigan	6.1	5.9	6.5
Massachusetts	4.9	5.6	5.7
New Jersey	5.0	6.3	5.5
Pennsylvania	5.5	4.0	5.0
Maryland	4.7	4.6	4.5
Texas	3.0	4.1	4.2
Illinois	4.0	3.9	4.1
Ohio	4.4	3.4	3.9
All other	47.1	45.1	45.9

NOTE: "All other" includes R&D performed in the 40 states not listed and in the District of Columbia, and R&D that could not be allocated to a specific location.

SOURCES: Science Resources Studies Division, National Science Foundation, *Geographic Patterns: R&D in the United States*, NSF 89-317 (Washington, DC: NSF, 1989); and appendix table 4-27.

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Research and Development Intensity of State Economies

Just as the ratio of R&D expenditures to GDP is used to gauge a country's commitment to R&D and measure the change in this commitment over time, the ratio of in-state R&D performance to gross state product (GSP) can be used to measure the research intensity of states' economic activity. Moreover, indicators that normalize for size of states' economies tend to facilitate more meaningful comparisons between states. For the United States, the R&D/GDP ratio was 2.6 percent in 1993. Twelve states and the District of Columbia had R&D/GSP ratios above the national average in that year. (See appendix table 4-28.)

Most states with relatively high R&D/GSP ratios are also among the leaders in terms of absolute levels of R&D expenditures. However, there are a few notable exceptions. For example, New Mexico—which ranks 17th in total R&D spending—has the highest R&D/GSP ratio. In 1993, it was 8.0 percent. New Mexico's research intensity is largely attributable to the considerable Federal support provided to the two FFRDCs located in the state.

Delaware is another state that is not among the largest in terms of R&D spending but that has a relatively high R&D/GDP ratio (4.9 percent in 1993). Delaware's high R&D/GSP ratio is a result of the chemical industry's comparatively large in-state R&D activities.

In contrast, California and New York, which lead the Nation in absolute dollars of total R&D performance, ranked only 7th and 19th, respectively, in terms of their economies' R&D intensity, with ratios of 4.3 percent and 2.2 percent, respectively. In 1993, there were 14 states with less than $500 million in R&D activity and R&D/GSP ratios under 1 percent. (See figure 4-15 and appendix table 4-28.)

State Cooperative Technology Programs

According to the most recent data, states spent a total of $385 million on Federal/State cooperative technology programs[26] in 1994, 22 percent more than in the previous year (Coburn, 1995). (See text table 4-5.) These programs fall into a number of different categories, the largest of which consists of those that support the development or application of technologies to meet market or production needs. In 1994, a total of $127 million was allocated for such programs, including $105 million to support technology development projects conducted at university-industry technology centers. Lesser amounts—ranging from $5 to $12 million—were used to finance university-industry research partnerships, government-industry consortia, and equipment and facility access programs.

The starting point for comparison among states has usually focused on their educational institutions. For example, all 50 states have adopted initiatives to support and facilitate public–private cooperation to develop and apply new technologies. Other types of state cooperative programs include technology (seed and venture capital) financing ($102 million in 1994), related educational initiatives ($83 million), and industry problem solving ($60 million).

Every state except Nevada, Rhode Island, and West Virginia provides financial support for at least one cooperative technology program. In 1994, state funding levels ranged from a low of $80,000 in Mississippi to a high of $37 million in North Carolina. The latter provides support to centers devoted to microelectronics and biotechnology R&D and to its Research Triangle Institute and Alliance for Competitive Technologies. North Carolina added almost $12 million to its annual budget for cooperative technology programs between 1993 and 1994, a 46-percent increase.

In addition to North Carolina, 12 other states budgeted more than $10 million each for cooperative technology programs in 1994. (See figure 4-16.) These 13 states accounted for three-quarters of the 1994 total for all states. Included in this group were 6 of the 10 states with the highest absolute levels of R&D spending—Pennsylvania, Texas, Ohio, New York, New Jersey, and Michigan. The others are all in the top 20, with 2 exceptions: Georgia (which ranks 25th overall) and Kansas (36th). These two states also had relatively low R&D/GSP ratios, 1.0 percent and 0.8 percent, respectively, in 1993.

Among the 13 states that spent the largest sums on cooperative technology programs, financial support between 1993 and 1994 doubled in two states—Connecticut and Maryland; it rose between 40 and 100 percent in Georgia, North Carolina, and Michigan, and fell slightly in Texas and New Jersey. Also, between 1994

[26]See footnote 13.

and 1995, New York's funding was expected to increase 60 percent and Virginia's was expected to fall 21 percent. In general, state S&T programs have weathered recession-driven budget cuts rather well, especially given the fiscal difficulties facing most states in recent years.

Experimental Program to Stimulate Competitive Research (EPSCoR)

NSF pioneered the Experimental Program to Stimulate Competitive Research (EPSCoR) concept in 1979. The program was established in response to congressional concern about the geographic concentration of Federal funding of academic R&D. Universities in states designated as EPSCoR states receive special, merit-based support aimed at strengthening their capability to compete successfully for Federal R&D funds. Since 1979, other Federal agencies have adopted their own EPSCoR programs with goals similar to those of NSF. In 1994, seven agencies spent a total of $65.7 million on EPSCoR programs, up from $56 million in 1993 and $46.4 million in 1992. NSF maintains the largest EPSCoR program, with expenditures totaling $31.9 million in 1994. (See text table 4-9.)

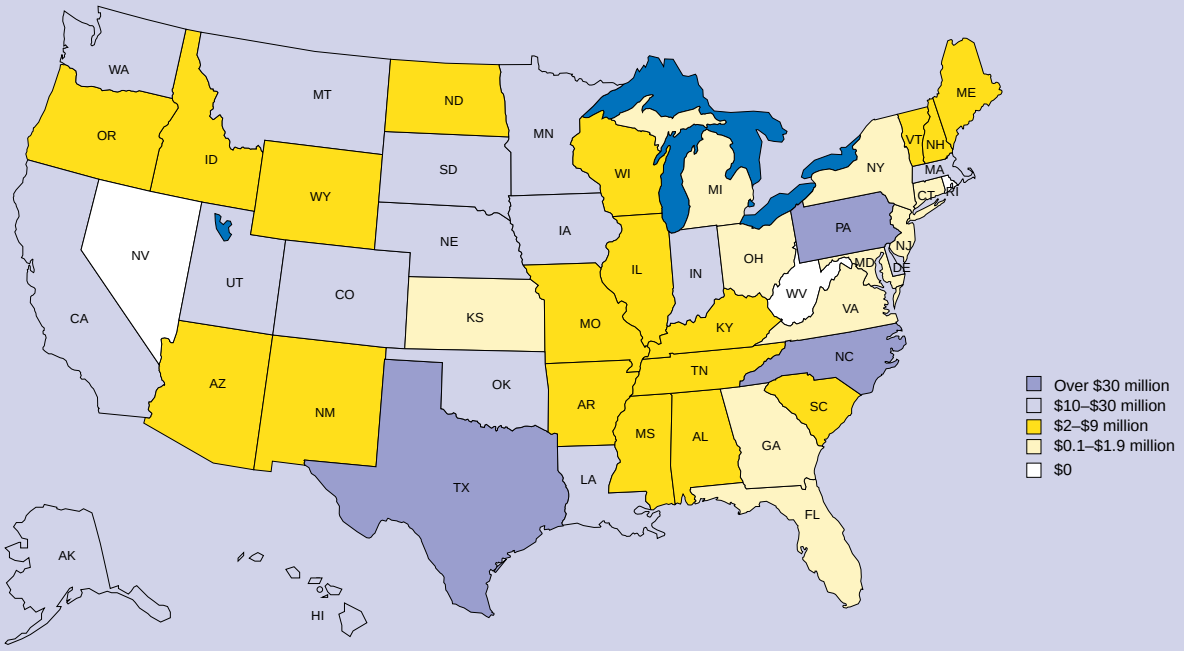
Defense-Related Issues

Changes in U.S. defense policy—in terms of both strategy and funding levels—have been dominating front-page headlines since the end of the Cold War. Not only is downsizing the military having an adverse impact on the economies of many communities throughout the country, but also defense-related S&T policies and programs are undergoing transition.

Although the threat of a potential superpower confrontation has diminished, other national security and economic considerations are now at the forefront, shaping U.S. defense posture. Current concerns include the country's role in extinguishing regional conflicts, curtailing nuclear proliferation, monitoring the pace and stability of democratic reforms in former Communist countries and in developing nations, and maintaining military leadership in the international marketplace where competition is driving the pace of technological change.

To meet these and other challenges, policymakers have been rethinking DOD's role in supporting S&T. In September 1994, DOD issued an updated version of its S&T strategy (Department of Defense, 1994). This statement confirms that technological supremacy remains the overriding goal of U.S. defense S&T policy, but it also includes two additional objectives—affordability and enhanced economic security—as factors determining S&T program priorities. Reduced defense budgets necessitate the careful targeting of limited R&D funds; hence, the inclusion of these additional goals which are also prominently featured in DOD's recently published S&T management guidelines. (See *Guiding Principles for Science and Technology Management.)*

Figure 4-16.
State cooperative technology program spending: 1994



See appendix table 4-28.

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DOD has identified a number of examples that illustrate how the adoption of new goals is affecting the funding of S&T activities. Emphasis on affordability and cost-effectiveness is manifested in the designation of three DOD-wide S&T initiatives—information technology, sensors, and modeling and simulation—as high-priority programs. Advancements in each of these technologies have already proven their worth in real-world scenarios such as Desert Storm and other regional conflicts and hold great potential for additional reductions in the cost of war in terms of both lives and equipment.

The inclusion of enhanced economic security as a major goal in allocating defense S&T expenditures is predicated on the assumption that DOD dollars should not only buy the latest state-of-the-art technology for the military but should also, whenever possible, leverage and perhaps accelerate the private sector's development of new products and services for the commercial marketplace. Thus, an all-out effort has been underway for the past few years to encourage and provide incentives (largely in the form of cost-sharing) for the public and private sectors to join forces to exploit promising technologies that have both defense and commercial applications.

The latest DOD pronouncement on so-called dual-use technology identified three pillars of this strategy: investment in R&D on dual-use technologies; dual produce, or integration, of military into commercial production; and insertion of commercial capabilities into military systems technologies.

The total FY 1995 DOD investment in dual-use research is $2.06 billion, or approximately 25 percent of the total DOD S&T budget.[27] This DOD research effort is concentrated in four focus areas: information technology ($392 million); advanced materials ($295 million); advanced manufacturing ($563 million); and advanced simulation and modeling ($83 million) (Department of Defense, 1995a).

[27]Basic research is not included in these dollar figures.

Text table 4-9.
EPSCoR program budgets, by agency

Agency	Fiscal year 1992	1993	1994
	Millions of dollars		
Total	46.4	56.0	65.7
Department of Agriculture	10.0	10.0	10.0
Department of Defense	10.0	12.0	6.0
Department of Energy	5.0	5.0	7.0
Department of Health and Human Services (NIH)	0.0	0.7	0.8
Environmental Protection Agency	0.0	0.8	2.0
National Aeronautics and Space Administration	2.9	3.0	8.0
National Science Foundation	18.5	24.5	31.9

EPSCR = Experimental Program to Stimulate Competitive Research

SOURCE: C. Coburn (editor), *Partnerships: A Compendium of State and Federal Cooperative Technology Programs* (Columbus, OH: Battelle Press, 1995).

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Guiding Principles for Science and Technology Management

The following are DOD's recently issued guiding principles for science and technology management:

(1) Transition technology to address warfare needs:
- ♦ Work with the warfighters;
- ♦ Move promising concepts rapidly;
- ♦ Insert technology into in-service systems; and
- ♦ Prevent technological surprise.

(2) Reduce cost:
- ♦ Use the best commercial products, practices, and capabilities;
- ♦ Simulate;
- ♦ Improve manufacturing processes;
- ♦ Consider environmental factors;
- ♦ Establish service affordability programs; and
- ♦ Reduce the cost of ownership.

(3) Strengthen the commercial-military industrial base:
- ♦ Develop dual-use technologies and processes;
- ♦ Formalize each service's program in dual-use;
- ♦ Sustain investments in priority technologies;
- ♦ Exploit commercial technologies;
- ♦ Strengthen technology transfer; and
- ♦ Develop field selected initiatives to apply technology to societal needs.

(4) Promote basic research:
- ♦ Support quality basic research;
- ♦ Sustain stable research funding;
- ♦ Educate future scientists and engineers; and
- ♦ Promote teamwork and partnerships.

(5) Ensure quality:
- ♦ Downsize, outsource, and restructure the DOD research and development test and evaluation (RDT&E) infrastructure;
- ♦ Retain a critical mass of internal expertise;
- ♦ Encourage innovation;
- ♦ Strengthen project Reliance;
- ♦ Enhance the quality of staff and facilities; and
- ♦ Monitor and collaborate in international science efforts (Department of Defense, 1994).

The centerpiece of these dual-use efforts has been the Technology Reinvestment Project. TRP is a multiagency effort led by the Advanced Research Projects Agency (DOD's central R&D organization). It is aimed at creating public–private partnerships to develop technologies for new products and processes that meet both military and commercial needs. In its first call for proposals, TRP received 2,850 submissions requesting a total of $8.5 billion in Federal funds, roughly 17 times the amount available. In the first round, $654 million was actually awarded. In the second round of competition, 39 out of 237 submitted proposals were funded, for a total of $188 million. After rescission, the 1995 funding level available for TRP was $208 million. The FY 1996 budget request was $500 million.

Within the broad array of dual-use technology projects, areas of special strategic importance have been identified. These include electronics manufacturing, flat panel displays, microelectronomechanical systems, advanced composites for aircraft, integrated high-performance turbine engineering technology, rotocraft technology, high-density data storage systems, and wireless communications.

Like the ATP, TRP has encountered political opposition in the 104th Congress. The most vocal critics have questioned TRP's relevance or are concerned that it represents an attempt at industrial policy inappropriate for the Government in a free-market system. Because of this difference of opinion on its usefulness, the future of TRP is uncertain.

International Comparisons

Absolute levels of R&D expenditures are indicators of the breadth and scope of a nation's S&T activities.[28] The relative strength of a particular country's R&D effort is further indicated by comparison with other major industrialized countries. This section provides such comparisons of international R&D spending patterns. The section contrasts performer and source expenditure patterns and reviews trend data.

U.S. leadership in terms of its financial investment in R&D vis-à-vis other countries narrowed considerably during the past 2 decades; more recently there has been a *worldwide* slowing in the growth of such funds. While R&D patterns by sector are quite similar across countries, national sources of support differ considerably. Foreign sources of R&D have been increasing in practically all countries.

Research and Development Funding by Source and Performer

The worldwide distribution of R&D performance is concentrated in several industrialized nations.[29] Of the approximately $380 billion in R&D expenditures estimated for Organisation for Economic Cooperation and Development (OECD) countries, 90 percent is expended in just seven.[30] The United States accounts for roughly 44 percent of the industrial world's R&D investment total and continues to outdistance, by far, the research investments made by all other countries. Not only did the United States spend more money on R&D activities in 1993 than did any other country, but also it spent more than the next four largest performers—Japan, Germany, France, and the United Kingdom—combined. Italy and Canada can also be considered major R&D performers, accounting for 3 and 2 percent, respectively, of the OECD R&D total. (See appendix table 4-33.) In only four other countries—the Netherlands, Sweden, Spain, and Switzerland—do R&D expenditures exceed 1 percent of the OECD R&D total (OECD, 1995).

The largest seven R&D-performing countries (G7) are markedly similar in terms of which sectors undertake the R&D. Industry was the leading R&D performer in each of the seven; performance shares in the early 1990s ranged from a little more than 70 percent in the United States and Japan, to somewhat less than 60 percent in Italy and Canada. Industry's share ranged between 60 percent and 70 percent in Germany, France, and the United Kingdom. (See figure 4-17 and appendix table 4-35.) The majority of industry's R&D performance was funded by industry itself in each of these countries, followed by government funding. Government's share of funding for industry R&D performance ranged from as little as 1 percent in Japan to about 20 percent in the United States and France.[31]

In most of the seven countries, the academic sector was the next largest R&D performer, followed by govern-

[28]The R&D data presented here for the major industrialized countries are obtained from reports to the OECD, which is the most reliable source of such international comparisons. The United Nations Educational, Scientific, and Cultural Organization (UNESCO) reports the few estimates for developing countries derived from systematic R&D data collection. There is a fairly high degree of consistency in the R&D data reported by OECD. Differences in reporting practices between countries are estimated to affect the R&D/GDP ratios by no more than 0.1 percent (ISPF, 1993). Data for countries reporting to UNESCO are often less comparable, principally because of differences in national statistical collection capabilities and definitions. In many such countries, however, there has been steady improvement in making these R&D statistics more internationally comparable over the past few years.

[29]Although several developing countries have greatly expanded the level of national resources they devote to civilian research efforts, the overall financial impact of their efforts is small compared with those of the large industrialized countries.

[30]Estimates are for 1993; see OECD (1995). Note that these estimates are based on reported R&D investments converted to U.S. dollars with PPP exchange rates. (See appendix table 4-22.) Although PPPs are not equivalent to R&D exchange rates per se, they better reflect differences in countries' laboratory costs than do market exchange rates. See section, *Purchasing Power Parities: Preferred Normalizer of International R&D Data* (NSB, 1993, pp. 98–99).

[31]The national totals for Europe, Canada, and Japan include the research component of general university funds (GUF) block grants provided by all levels of government to the academic sector. Therefore, at least conceptually, the totals include both academia's separately budgeted research and research undertaken as part of universities' departmental R&D activities. In the United States, the Federal Government generally does not provide research support through a GUF equivalent, preferring instead to support specific separately budgeted R&D projects. On the other hand, a fair amount of state govern-

ment laboratories. Only in France and Italy was government's R&D performance (which included spending in several nonprivatized industries, as well as in some sizable government laboratories) slightly larger than that of academia. Government's R&D performance share was smallest in Japan and the United States, at about 10 percent of the total.

Consistent with performing most of these countries' R&D activities, the industrial sector provides the greatest proportion of financial support for R&D. Shares for this sector, however, differed substantially from one country to the next. Industry provided more than 70 percent of R&D funds in Japan; 60 percent in Germany; about 50 percent in the United States, the United Kingdom, and Italy; and somewhat less in France and Canada. (See figure 4-17.) In each of these seven countries, government was the second largest source of R&D funding and also provided most of the funds used for academic R&D performance. Foreign funding—predominately from industry for R&D performed by industry—is an important and growing funding source in several countries. (See Foreign R&D in The United States in this chapter.) The R&D funding share represented by funds from abroad ranged from 12 percent in the United Kingdom to a mere 0.1 percent in Japan. In the United States, almost 7 percent of funds spent on R&D in 1993 are estimated to have come from majority-owned affiliates of foreign firms investing domestically. This amount was up considerably from the 2-percent funding share provided by foreign firms in 1980.[32] (See appendix tables 4-35 and 4-36.)

Total Research and Development Trends

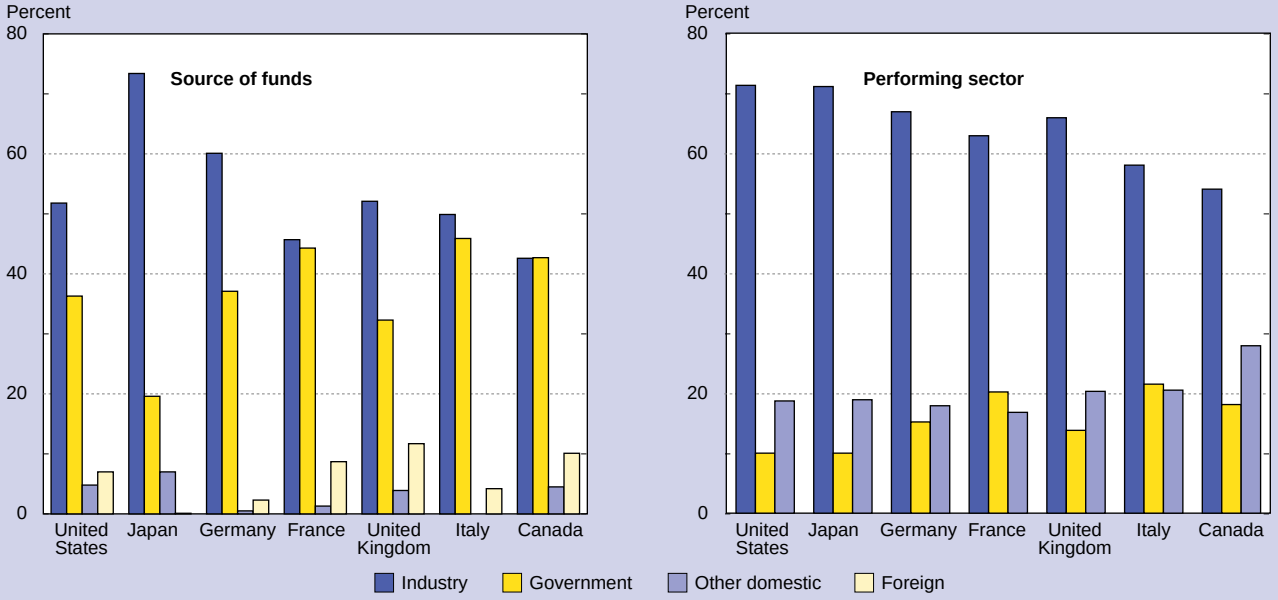
Total R&D expenditures stagnated or declined in each of the largest R&D-performing countries in the early 1990s. Indeed, for more than a decade, these G7 countries have displayed similar aggregate R&D trends: substantial inflation-adjusted R&D growth in the early 1980s, followed by a general tapering off in the late 1980s, and then level or declining real R&D expenditures into the 1990s. For most of these countries, economic recessions and general budgetary constraints had the effect of slowing both industrial and government sources of R&D support. In particular, both factors have contributed to the major reversal of R&D trends in Japan, where R&D spending has declined recently after experiencing inflation-adjusted gains of about 8 percent annually during the previous decade. The same is true for the United Kingdom and Italy, where real growth in the 1980s gave way to declining R&D expenditures after taking into account overall inflation. (See figure 4-18.)

Additionally, geopolitical changes have resulted in cutbacks in government support for defense-related R&D that, in turn, have reduced reported national R&D growth

ment funding probably does support departmental research at public universities in the United States. Data on departmental research, which is considered an integral part of instructional programs, generally are not maintained by universities. U.S. totals may thus be underestimated relative to the R&D effort reported for other countries.

[32]Unlike for other countries, there are no data on foreign sources of U.S. R&D performance. The figures used here to approximate such foreign involvement are derived from the estimated percentage of U.S. industrial performance undertaken by majority-owned (that is, 50 percent or more) non-bank U.S. affiliates of foreign companies.

Figure 4-17.
R&D expenditures, by country, source, and performer: 1993



NOTE: Foreign performers are included in the "industry" and "other domestics" sectors.
See appendix tables 4-35 and 4-36.

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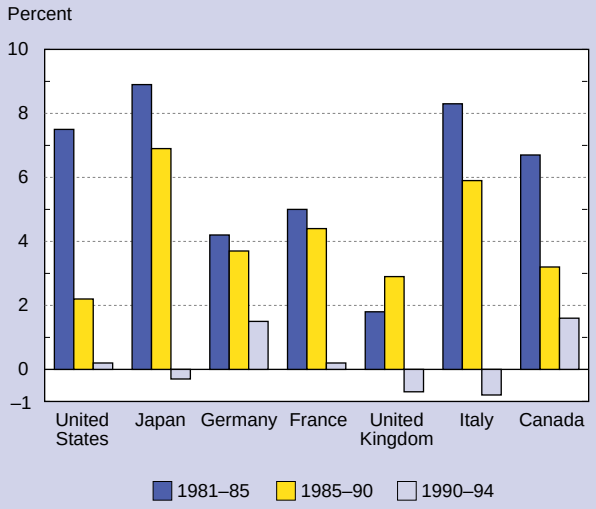
Figure 4-18.
Rates of change in total R&D spending, by selected countries



NOTE: Rates of average annual change based on inflation-adjusted currencies.

See appendix table 4-33.

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patterns in some countries, most notably in the United States and France. For Germany, the integration of the former East German science and technology system into that of West Germany's market economy resulted in an apparent jump in the nation's R&D effort in 1991, only to have since been scaled back in an effort to restructure and close inefficient, inappropriate, and redundant research institutions (Government of the Federal Republic of Germany, 1993; Meyer-Krahmer, 1992).

The drop in Germany's total R&D effort is indicated by recent trends in its R&D-to-GDP ratio, a metric that is one of the most widely used indicators of a country's commitment to scientific knowledge growth and technology development. (See figure 4-19.) In Germany, the ratio has fallen from 2.9 percent at the end of the 1980s, before reunification, to its current level of 2.5. This pattern is not, however, restricted to Germany. In the United States, R&D's share of GDP similarly declined from 2.8 percent in 1991 to an estimated 2.4 percent in 1995. In fact, the latest R&D/GDP ratio in each of the G7 countries is no higher than the ratio reported at the start of the 1990s. In France, Germany, Japan,[33] the United Kingdom, and the United States, R&D/GDP ratios appear to have drifted back from recent peaks to the 2.2- to 2.7-percent range. In Italy and Canada, which also have confronted economic and budgetary constraints, this ratio leveled off at about 1.3 and 1.5 percent, respectively.

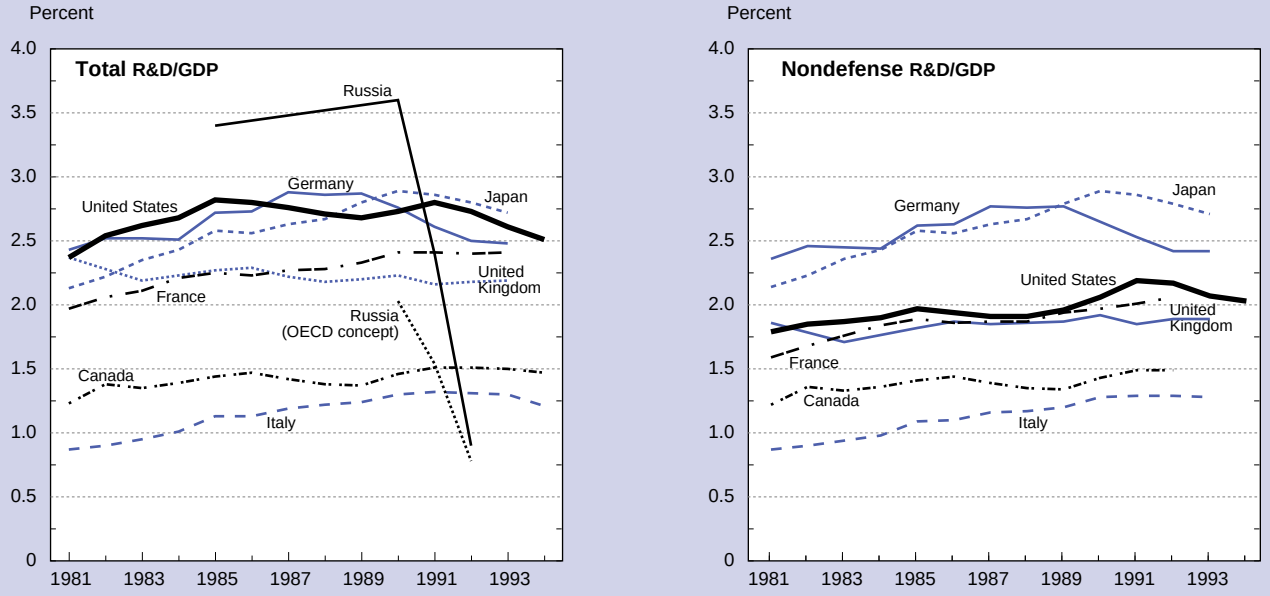
Moreover, the recent slowdown/decline in R&D spending is not confined to the OECD's largest industrialized countries. R&D growth during the 1990s in many of the smaller or less technologically advanced European countries has been slower than the growth reported for the 1980s. This is particularly true among Eastern European countries and the former Soviet Union, where the severe market and industrial adjustments necessitated in transitioning to market economies have been accompanied by an even more severe downsizing of R&D activities (European Commission, 1994).

Although such figures should be treated cautiously, the R&D/GDP ratio shown for Russia displays well the overall decline in the country's indigenous R&D capabilities since the collapse of the Soviet Union. (See figure 4-19.) As recently as 1990, R&D accounted for about 3.5 percent of Russia's gross economic product (Dezhina, 1994). Perhaps two-thirds of that amount was expended in military laboratories, about 10 percent was directed toward basic research in a multitude of fundamental science fields, and most of the remainder was classified as applied industrial research which overlapped with defense-related R&D (Schweitzer, 1995). By 1992, government support for R&D had dwindled to less than 1 percent of GDP and nongovernmental sources were generally unknown.[34] Indeed, according to the Russian Center for Science Research and Statistics (1995), the country's total R&D—calculated according to OECD international standards—dropped from 2 percent of GDP in 1990 to 0.8 percent in 1992. Reflecting the lack of core budgets, entire research institutes have been closed—including many of the well-equipped laboratories of the former military-industrial complex—and an estimated 30 percent of all researchers have left for the commercial sector, for retirement, or for other reasons, including emigration, since 1991. According to statistics released in 1994 by the Russian Ministry of Science and Technological Policy, the overall R&D budget now represents less than 0.5 percent of GDP (Schweitzer, 1995). About two-thirds of the Federal budget appropri-

[33]The R&D data reported here for Japan generally are those adjusted by the OECD from the official Japanese statistics in order to make them more comparable with international standards. In Japan, data for R&D personnel are expressed as the number of people working mainly on R&D rather than in terms of full-time equivalent. Consequently, R&D labor cost data—and therefore total R&D expenditures—are overestimated by international standards. Based on estimates obtained from recent Japanese studies, the OECD reports adjusted Japanese R&D totals that are about 15 percent lower than the official R&D series. For example, the adjusted Japan R&D/GDP ratios reported here are 2.1 percent for 1981, 2.9 percent for 1990, and 2.7 percent for 1993. The unadjusted ratios are 2.3 percent for 1981, 3.1 percent for 1990, and 2.9 percent for 1993.

[34]These trend statistics are taken from Dezhina (1994) and represent Federal budgetary expenditures on science as a percentage of GNP. These figures may be viewed as a rather comprehensive accounting of the Russian R&D total (up through 1992) since business enterprises—in other words, nongovernmental resources—accounted for only 0.1 percent of total domestic R&D finances, and foreign R&D funding was not prevalent. Although there is some uncertainty as to the defense versus nondefense components of Russia's R&D total, as well as the more general question of what is being counted in these totals, the key point is undeniable: Federal Government R&D financing has been radically reduced in the 1990s and other domestic sources of financing are practically negligible.

Figure 4-19.
R&D as a percentage of GDP, by country



NOTES: German data for 1981–90 are for the former West Germany. Russian data provide a range for comparison.

See appendix tables 4-33 and 4-34.

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ations are now for civilian R&D, although about 40 percent of this nondefense R&D is performed within defense industries (Russian Center for Science Research and Statistics, 1995). Furthermore, by the end of 1994, it is estimated that probably more than one-half of civilian R&D was financed from foreign sources.

Nondefense Research and Development Trends

With the end of the Cold War and the recent policy focus on economic competitiveness and commercialization of research results, probably a more relevant indicator of a nation's scientific and technological strength is the ratio of nondefense R&D expenditures to GDP.[35] Intercountry comparisons of R&D expenditures change dramatically when defense-related expenditures are excluded. The nondefense R&D/GDP ratios of both Japan (2.7 percent) and Germany (2.4 percent) considerably exceeded that of the United States (2.0 percent) in 1993 and have done so for years. (See figure 4-19 and appendix table 4-34.) The nondefense R&D ratio of France matched the ratio of the United States; the ratios of the United Kingdom (1.9 percent), Canada (1.5 percent), and Italy (1.3 percent) were somewhat lower. As with the total R&D ratios, the nondefense R&D-to-GDP shares were level or falling in the United States, Germany, and Japan during the early 1990s.

In absolute dollar terms, the U.S. international position was markedly different—and comparatively more favorable—than indicated by the nondefense R&D/GDP ratios. Between 1981 and 1993, growth in U.S. nondefense R&D spending was rather similar to growth in other industrial countries, save for Japan, whose nondefense R&D expenditure growth was notably faster than that in the United States. Thus, as a percentage of the U.S. nondefense R&D total, comparable Japanese spending jumped from 42 percent in 1981 to 53 percent in 1993. (See appendix table 4-34.) During this period, Germany's annual spending was equal to 26 to 30 percent of U.S. nondefense R&D spending, while France's annual spending was equivalent to 16 to 18 percent, and the United Kingdom's annual spending was between 14 and 17 percent. In 1993, the combined nondefense R&D spending in these four countries equaled $119 billion (in constant dollars), somewhat greater than nondefense R&D spending in the United States ($106 billion in constant dollars).

Government Focus by National Objective

Numerous changes have been occurring domestically and worldwide that have caused the R&D landscape to be in considerable flux. The most notable changes include the demise of the Soviet Union, the transition of Eastern European communist systems into market

[35]This is not to say that defense-related R&D does not benefit the commercial sector. There unquestionably have been technological spillovers from defense to the civilian sector. But almost as certainly, the benefits are less than if these same resources had been allocated directly to commercial R&D activities. Moreover, considerable anecdotal evidence indicates that the technological flow is now more commonly from commercial markets to defense applications, rather than the reverse.

economies, an increase in international economic challenges to the preeminence of U.S. competitiveness, public and private sector demands for budgetary austerity and accountability, and realignments within industry and at research universities. This means the ultimate determination of Federal funding priorities—which are mirrored in the functional focus of Federal R&D support—is subject to more than the usual political uncertainty.

U.S. Funding Priorities

Federal R&D funding priorities shifted overwhelmingly toward defense programs in the 1980s; these included both DOD programs and nuclear weapons research funded by the DOE.[36] Defense R&D spending peaked in 1987 at $39 billion (inflation-adjusted 1987 dollars), when it accounted for 69 percent of the Federal R&D total. Since then, however, the data reflect a distinct de-emphasis on defense priorities as well as the current Administration's stated intention to shift the focus of Federal R&D support back to an even military–civilian split by 1998 (Clinton and Gore, 1993). (See figure 4-20 and appendix table 4-29.) Proposed Federal R&D funding for defense-related activities accounts for 53 percent of the 1996 total.

Of the Federal nondefense functions, health—particularly the R&D programs of HHS—experienced the largest inflation-adjusted R&D funding growth since the early 1980s. In particular, AIDS-related research has grown substantially and now accounts for roughly 11 percent of Federal health R&D funds, which is second only to the 16-percent share directed toward cancer research. Funding for space research has shown a bit of a roller-coaster pattern, dropping precipitously in the early 1980s and then rising rather steadily thereafter. Most of its R&D funding growth has been in support of Space Station Freedom.[37]

Among the other major functional recipients of Federal R&D funding, energy displays the largest sustained decline in support and is currently funded about 60 percent less (constant dollars) than at the start of the 1980s.[38] Research funding for general science programs,[39] which include those of NSF and DOE, has fared no better—and has done relatively much worse—than that for many other major civilian budgetary categories during the past 15 years. (For agency-specific details, see *Patterns of Federal R&D Support* in this chapter.)

The following five functions account for 89 percent of proposed 1996 R&D budget authority:

- National defense—53 percent, including DOD's technologies support and DOE's environmental restoration and waste management research;
- Health—17 percent, which is roughly comparable with the percentage of nonfederal R&D support that is health-related (see *Health Continues to Absorb Increasing Share of National Research and Development Budget* and figure 4-21);
- Space research and technology—11 percent;
- Energy—4 percent; and
- General science—4 percent.

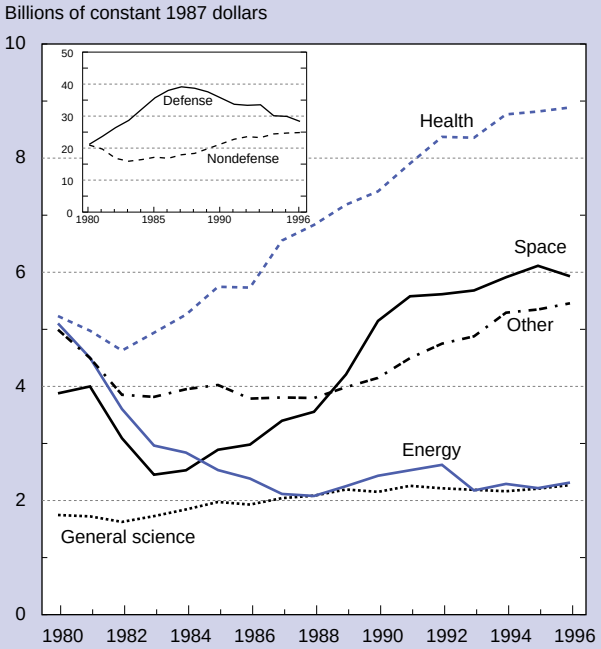
[36]The Office of Management and Budget (OMB) classifies all activities within the Federal budget into 20 functional categories. The budget function classification system provides a means to classify budgetary resources according to the national need being addressed. There are 15 functions that contain Federal R&D programs. For definitions and details, see SRS (1996). Data reported here reflect estimates for R&D programs contained in the administration's 1996 budget proposal that was submitted to Congress in January 1995 (OMB, 1995). Notably, each specific activity is assigned to only one object code so that programs with multiple objectives will be classified only once under the program's primary functional objective. For example, except for those of the Army Corps of Engineers, all R&D activities sponsored by the DOD are classified as defense, even though some activities have secondary objectives such as health, space, or commerce (that is, defense conversion activities). Consequently, these totals are indicative of trends but not necessarily conclusive. See recent GAO reports for a coverage of the Federal Government's total funding by function (GAO, 1995a; 1995b; 1995c).

[37]Funding for the Space Station rose from $22 million in 1984, the first year for which this program received a separate budget line item, to $2 billion in 1994 (AAAS, 1994).

[38]For an extensive review of DOE's energy programs, including their placement in a broader global context and in relation to industry's long-term energy R&D investments, see Department of Energy (1995b), informally known as the Yergin Report.

[39]Research activities classified under this "general science" budget category are seen as contributing more broadly to the Nation's science and engineering base than are basic research programs that support agency missions.

Figure 4-20.
Federal R&D funding, by budget function



NOTE: "Other" includes all nondefense functions not separately graphed, such as agriculture and transportation.

See appendix table 4-29. *Science & Engineering Indicators – 1996*

Health Continues to Absorb Increasing Share of National Research and Development Budget

Data on the source and performance of health-related R&D have been collected annually by NIH (Department of Health and Human Services, 1993). These tabulations are more comprehensive than the Office of Management and Budget function data presented elsewhere, because NIH attempts to include

- Health-related components of all agencies' R&D obligations, regardless of their formal budget function classification;
- Expenditures from nonfederal government sources; and
- Health R&D data from private, nonfederal sources—primarily industry, but also nonprofit organizations such as the Howard Hughes Medical Institute.

According to the NIH data, a total of $32.9 billion was spent on health R&D in the United States in 1994. (See appendix table 4-31.) This is estimated to be nearly 20 percent of total U.S. R&D expenditures in that year. Health R&D, as a percentage of total R&D, has been increasing steadily since 1986; in that year, it was approximately 12 percent of total R&D expenditures. (See figure 4-21.)

The private sector now provides most of the funding (56 percent) for health R&D in the United States. That was not always the case. Prior to 1992, the public sector (including Federal, state, and local government) was the leading source of funds spent on health R&D.

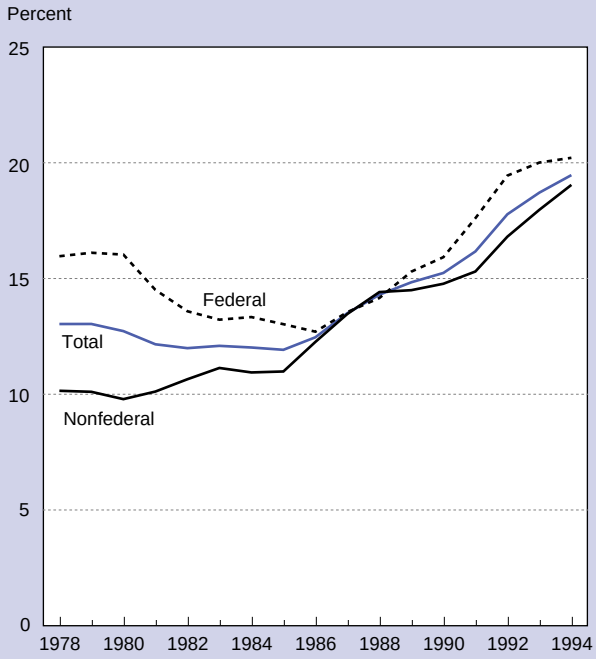
In 1994, industrial firms and nonprofit organizations supplied an estimated $17.1 billion and $1.3 billion, respectively, for health-related R&D. Private sector health R&D funding more than doubled between 1988 and 1994. Most of this increase is attributable to pharmaceutical and biotechnology companies' R&D activities, which have been expanding rapidly in recent years. (See Industrial Research and Development in this chapter.)

The public sector provided an estimated $14.5 billion in funds for health R&D in 1994. More than 70 percent of this money ($12.3 billion) was supplied by NIH; state and local governments furnished $2.2 billion.

About 20 percent of all Federal R&D money supports health-related activities, up from 13 percent in 1986. The increase in Federal support, however, has been lagging behind the increase in the private sector. Although Government support for health R&D increased steadily in the late 1980s and early 1990s (28 percent in real terms between 1986 and 1992), the rate of increase slowed after 1992. In fact, Government health R&D investment did not keep pace with inflation between 1992 and 1994.

In the United States, $9 out of every $10 spent on health R&D performed in the United States are used to finance work undertaken in private laboratories. Most of the R&D is performed by industrial firms (almost $14 billion in 1994), followed by universities and colleges($10 billion). Nonprofit organizations spent $2.7 billion in 1994, slightly less than the total amount ($3.0 billion) spent in the public sector (mostly in NIH laboratories). In the late 1980s and early 1990s, industry increased its share of health-related R&D performance in the United States while the proportion conducted in the academic and Federal sectors fell during the same period.

Figure 4-21.
Funding of health R&D as a percentage of total R&D, by source



See appendix tables 4-5 and 4-31.

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Two other functional areas of Federal concern each account for 3 percent of R&D budget authority and for most of the gain in the all-inclusive "other" category: (1) transportation, which is dominated by aeronautical research funded by NASA, and (2) natural resources and the environment. (See figure 4-20.) Environmental research, in particular, has been identified as an area of specific Government interest that has received increased funding from the present administration.[40]

The largest single percentage increase for R&D in 1996 was proposed in the Commerce and Housing Credit (CHC) function—jumping 15 percent over 1995—under which is included R&D support at NIST and comprises both its intramural research program and extramural ATP support for precompetitive generic technologies. Should NIST receive full funding of $720 million, the CHC function would account for 1 percent of all Federal R&D, or five times its 0.2-percent share held in 1990. Current budgetary deliberations by the Congress, however, appear to reduce spending for a number of these activities and functions.

International Comparisons

A breakdown of public expenditures by major socioeconomic objectives provides insight on governmental priorities, which differ considerably across countries.[41] In the United States during 1994, 55 percent of the government's $68 billion R&D investment was devoted to national defense, compared with 45 percent in the United Kingdom (of the $9 billion government total), 34 percent in France (of the $14 billion total), and 10 percent or less each in Germany, Italy, Canada, and Japan. (See figure 4-22.) Cutbacks in defense R&D are expected to continue in the United States, United Kingdom, and France.

Another emphasis is health-related R&D. The U.S. Government devoted 17 percent of its R&D investment to 1994 on health-related R&D; this emphasis is especially notable in its support for life sciences given to academic and similar institutions. The emphasis on life sciences and health-related research is much more pronounced in the United States than in other countries[42] and is reflected in research output trends. (See chapter 5, Academic Research and Development: Infrastructure and Performance.)

Japanese and German government R&D appropriations in 1994 were invested relatively heavily (51 percent of the $18 billion and $15 billion totals respectively) in the advancement of knowledge (which is combined support for advancement of research and general university funds, or GUF). Indeed, the GUF component of advancement of knowledge, for which there is no comparable counterpart in the United States, represents the largest part of government R&D expenditure in most countries.[43] Energy-related activities accounted for the second largest share of Japanese R&D support (21 percent of governmental R&D funds), reflecting the country's concern with its high dependence on foreign sources of energy. In Canada, 12 percent of the government's $3 billion R&D funding is directed toward agriculture.

In each of the four European countries and Canada, industrial development accounted for 7 percent or more of governmental R&D funding, reaching 16 percent of Italy's $8 billion government total. Industrial development accounted for 4 percent of the Japanese total, but just 0.6 percent of U.S. R&D. The latter figure—which may be understated relative to other countries as a result

[40]Available statistics on such funding, however, tend not to capture the full extent of these environmentally related R&D activities. Based on the programmatic budgetary classifications used in this section, $2.2 billion was slated for natural resources and the environment in fiscal year 1996. Official budget documents (OMB, 1995)—not constrained by formal classification schemes—reported an environmental R&D investment of more than $5.5 billion in 1996, which included $2.2 billion for the U.S. Global Change Research Program. See also National Science and Technology Council (1995a and 1995b) for further discussion of recent administration efforts directed toward environmental research and the development of a national environmental technology strategy.

[41]Data on the socioeconomic objectives of R&D funding are rarely obtained by special surveys, but rather are generally extracted in some way from national budgets. Since these budgets already have their own methodology and terminology, these R&D funding data are subject to comparability constraints not placed on other types of international R&D data sets. Notably, although each country adheres to the same criteria for distributing their R&D by objective (as outlined in OECD, 1981; 1994b), the actual classification may differ among countries because of differences in the primary objective of the various funding agents. Note also that these data are of government R&D funds only, which account for widely divergent shares and absolute amounts of each country's R&D total. The classification of the U.S. totals presented here are generally consistent with those presented previously in this chapter.

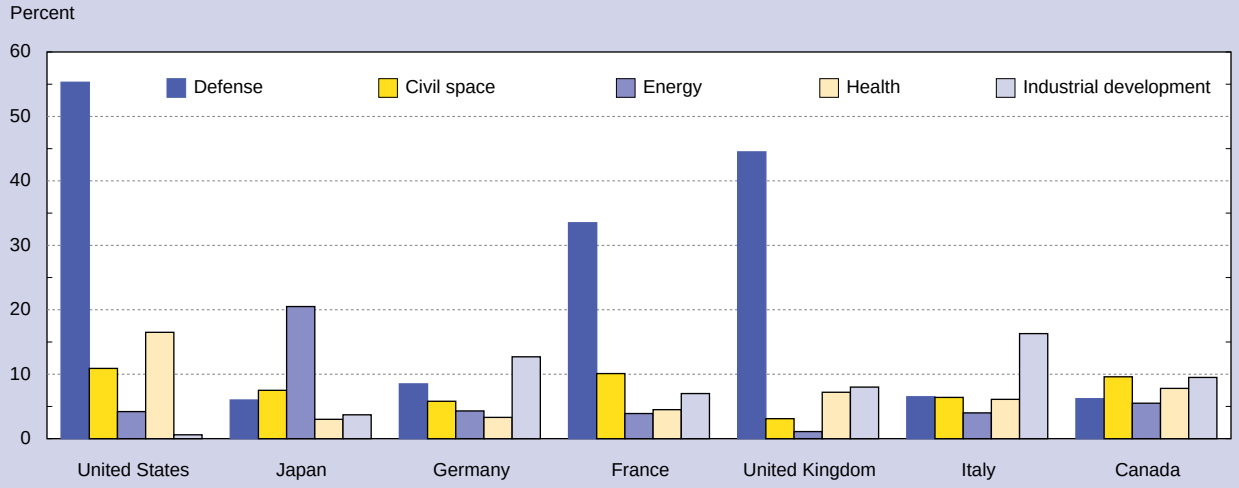
[42]For detailed comparisons—by field of science—of government (national, state, and local) funding of (1) academic research (including for separately budgeted research and research supported out of general university funds) and (2) academically related research (such as that of university-administered FFRDCs and the NIH intramural program) in the United States, United Kingdom, Netherlands, France, Germany, and Japan, see Irvine, Martin, and Isard (1990). For further comparisons with Canada and Australia, see Martin and Irvine (1992). Note that trends in academic and academically related research should not be equated with basic research trends.

[43]In the United States, advancement of knowledge is a budgetary category for research unrelated to a specific national objective. Furthermore, whereas GUF is reported separately for Japan and European countries, the United States does not have an equivalent GUF category: Funds to the university sector are distributed among the objectives of the Federal agencies that provide the R&D funds.

The treatment of GUF is one of the major areas of difficulty in making international R&D comparisons. In many countries other than the United States, governments support academic research primarily through large block grants that are used at the discretion of each individual higher education institution to cover administrative, teaching, and research costs. Only the R&D component of these GUFs are included in national R&D statistics, but problems arise in identifying how much the R&D component is and the objective of the research.

Government GUF support is in addition to support that is provided in the form of earmarked, directed, or project-specific grants and contracts (and thereby can be assigned to specific socioeconomic categories). In the United States, the Federal Government (although not necessarily state governments) is much more directly involved in choosing which academic research projects are supported than in Europe and elsewhere. Thus, these socioeconomic data are indicative not only of relative international funding priorities, but also of funding mechanisms and philosophies as to the best methods for financing research. For the 1993–94 period, the GUF portion of total national governmental R&D support was between 37 and 42 percent in Japan, Italy, and Germany, and between 14 and 21 percent in the United Kingdom, Canada, and France.

Figure 4-22.
Government R&D support, by country and socioeconomic objective: early 1990s



NOTES: Details do not add to 100 percent because funding for some objectives (for example, advancement of knowledge) is not graphed. R&D is classified according to its primary government objective, although it may support any number of complimentary goals. For example, defense R&D with commercial spin-offs is classified as supporting defense, not industrial development.

See appendix table 4-32.

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of compilation differences—has recently increased, reflecting the current Administration's programs that provide investment in commercially relevant R&D programs—notably within NIST.

These aggregate socioeconomic data, however, only begin to capture the extraordinary changes that have taken place in the international arena over the past several years and the resultant shifts in countries' S&T policy directions. According to a recent report released by the OECD (1994a), a number of commonalities among countries are worth highlighting:

- Governments clearly attach great importance to science and technology, but countries are finding it increasingly difficult to maintain previous funding levels in the face of economic problems. Budget allocations for large (expensive) S&T projects are particularly vulnerable, thereby making international cooperation more attractive as an option;
- Many countries have shifted policy emphasis toward support for technology, with governments allocating funds to innovation in order to maintain economic competitiveness and stimulate growth;
- Governments have made serious efforts to streamline their R&D systems, have restructured administrative bodies and engaged in priority setting measures, and have increased emphasis on accountability;
- There is a growing emphasis on directing S&T toward meeting the needs of society. This is reflected in higher expenditures for environmental and medical research; however, there generally has been a concurrent decline in energy and transportation research;
- Geopolitical upheavals in the early 1990s have engendered modifications in S&T policy as is reflected in declining defense R&D expenditures and a shift in the focus of international cooperation toward the former Soviet bloc and countries of the Asia-Pacific region; and
- The increasingly knowledge-intensive economy has given rise to growing concerns about the adequacy of scientific education and technical training.

Internationalization of Research and Development and Technology

Movement toward the internationalization—often termed globalization—of R&D activities has expanded considerably during the past decade. This growth is exhibited in each of the R&D performing sectors. Gains in cross-country academic research collaboration are indicated by the substantial increase in international coauthorships during the past decade. (See chapter 5, Academic Research and Development: Infrastructure and Performance.) In the public sector, the rise in international cooperation has been rapid, and these activities now account for up to 10 percent of government R&D expenditures in some countries. Interactions with Asian countries particularly seem to be on the rise, and significant programs have been launched by Europe and the United States with countries of the former Eastern bloc, especially Russia. International collaboration in scientific research involving extremely large—megascience—projects has also grown substantially, reflecting scientific and budgetary realities. Excellent science is not the

domain of any single country and many scientific problems involve major instrumentation and facility costs that appear much more affordable when cost-sharing arrangements are in place. Additionally, some scientific problems, such as global change research, mandate an international effort.[44]

In the private sector, international R&D collaboration is also on the rise, as is indicated by the growth of formal cooperative partnerships between firms and of overseas R&D activities undertaken under contracts, through subsidiaries, and with the establishment of independent research facilities.[45] Although the reasons for this growth are complex, generally it appears that multilateral industrial R&D efforts are a response to the same competitive factors affecting all industries: rising R&D costs and risks in product development, shortened product life cycles, increasing multidisciplinary complexity of technologies, and intense foreign competition in domestic and global markets.

International Strategic Technology Alliances

There is evidence of a sharp increase in transnational joint research funding throughout the industrialized world that began in the early 1980s and accelerated as the decade wore on.[46] Specifically, the number of known international multifirm R&D alliances grew steadily. In 1973–76, there were 86 alliances; in 1977–80, there were 177; in 1981–84, 509; and in 1985–88, there were 988 (Hagedoorn, 1990). More recently tabulated data indicate a tapering off in the creation of new international technology alliances reported for the 1990s, but that—at least for several core technologies, such as information technologies, biotechnology, and new materials—firms apparently have not reached a saturation point in establishing such R&D partnerships. For the period from 1990–94, the total number of newly formed strategic alliances was at a level comparable with the number entered during the mid-1980s. (See appendix table 4-37.)

As the numbers have increased, the forms of cooperative activity have changed somewhat. The most prevalent modes of global industrial R&D cooperation in the 1970s were joint ventures and research corporations. In these arrangements, at least two companies share equity investments to form a separate and distinct company; profits and losses are shared according to the equity investment.[47] In the second half of the 1980s and continuing into the 1990s, joint nonequity R&D agreements became the most important form of partnership. Under such agreements, two or more companies organize joint R&D activities to reduce costs and minimize risk, while pursuing similar innovations. The participants share technologies but have no joint equity linkages.

Formation of these so-called strategic technology alliances (both equity and nonequity arrangements) are particularly extensive among high-tech firms; data are available for the three advanced technologies listed above.[48] Reflecting the general rise in importance of information technologies (IT) across industries and throughout society, growth in IT research alliances far outdistanced the growth related to biotechnology and materials. (See figure 4-23.) Between 1980 and 1994,

[44]See Carnegie Commission (1992) for a review of recent trends in U.S. foreign S&T policy, including a summary of several indicators (for example, changes in State Department S&T staffing and the number of international S&T agreements). For a review of issues related to megascience, see OECD (1994a) and OTA (1995a). In particular, since 1992, OECD (1993) has sponsored an international Megascience Forum to coordinate and exchange information on megascience projects and programs.

[45]For an extensive review of U.S. globalization trends in trade and investment, including business research and technology development, see recent Office of Technology Assessment reports (1993; 1994).

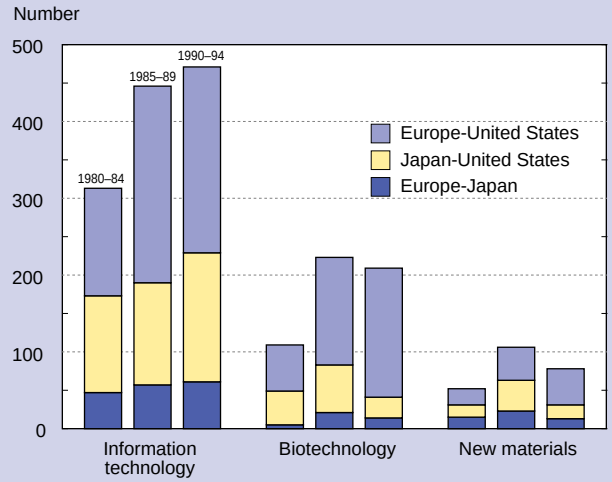
[46]Information in this section is drawn from an extensive data base compiled in the Netherlands (Maastricht Economic Research Institute on Innovation and Technology's Co-Operative Agreements and Technology Indicators data base—MERIT-CATI) on more than 10,000 interfirm cooperative agreements involving thousands of different parent companies. In the CATI data base, only interfirm agreements that contain some arrangements for transferring technology or joint research are collected. The data summarized here extend by 4 years the information presented in Hagedoorn and Schakenraad (1993). These counts are restricted to strategic technology partnerships such as joint ventures for which R&D or technology sharing is a major objective, research corporations, joint R&D pacts, and minority holdings coupled with research contracts.

CATI is a literature-based data base; its key sources are newspapers, journal articles, books, and specialized journals that report on business events. CATI's main drawbacks and limitations are that (1) data are limited to activities publicized by the firm, (2) agreements involving small firms are likely to be underrepresented, (3) reports in the popular press are likely to be incomplete, and (4) it probably reflects a bias because it draws primarily from English-language materials. CATI information should therefore be viewed as indicative and not comprehensive.

[47]Joint ventures are companies that have shared R&D as a specific company objective, in addition to production, marketing, and sales. Research corporations are joint R&D ventures with distinctive research programs.

[48]For a review of strategic partnering trends in other technologies (chemicals, aviation/defense, automotive, and heavy electrical equipment), see Hagedoorn (1995).

Figure 4-23.
Number of new strategic technology alliances, by industry and region



See appendix table 4-37.

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more than 2,800 IT alliances were reported between firms involved in computer software and hardware, telecommunications, industrial automation, and microelectronics. Internationally, the largest number of such relationships was between U.S. and European firms, although the number of intra-European alliances was also substantial. (See appendix table 4-38.)

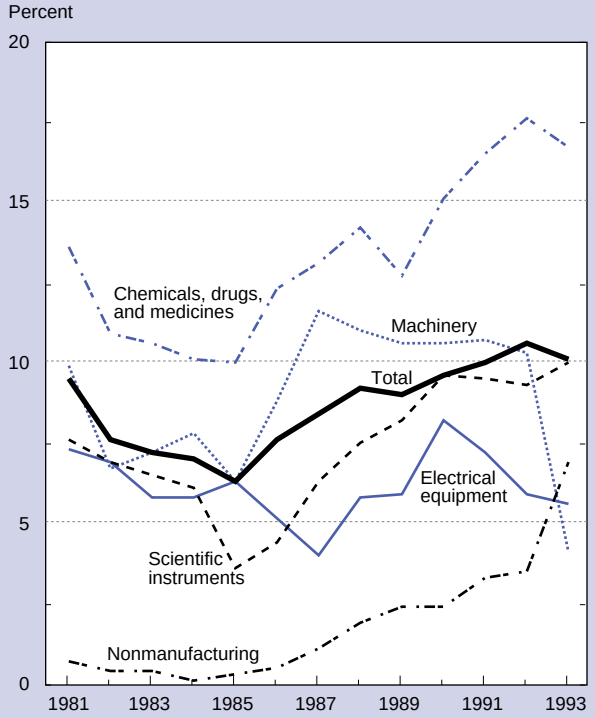
U.S. Industry's Overseas Research and Development

Stiff international competition in research-intensive and high-technology products, as well as market opportunities, have compelled U.S. industry to expand its overseas research activities.[49] There is little evidence, however, that much of the R&D undertaken abroad is meant to displace domestic R&D. Rather, the R&D that moves abroad tends to follow overseas production activities and is intended to support firms' foreign business growth. For example, such research is typically directed toward supporting production facilities, customizing products to local market demands, and tracking and capitalizing on foreign technological advancements (OTA, 1994).

Since 1985, U.S. firms generally increased their annual funding of R&D performed outside the country. (See appendix table 4-40.) Indeed, from 1985 to 1993, U.S. firms' investment in overseas R&D increased three times faster than investment in R&D performed domestically (9.3- versus 3.1-percent average annual constant dollar growth). Accounting for the equivalent of about 6 percent of industry's domestic R&D funding in 1985, overseas R&D now amounts to more than 10 percent of U.S. industry's on-shore R&D expenditures. (See figure 4-24.) Additionally, according to data from the Bureau of Economic Analysis (BEA), the majority-owned (i.e., 50 percent or more) foreign affiliate share of U.S. multinational companies' worldwide R&D expenditures increased from 9 percent in 1982 to 13 percent in 1990, where it remained through 1993 (Mataloni, 1995).

R&D investment by U.S. companies and their foreign subsidiaries in the chemicals (including pharmaceuticals and industrial chemicals) industry accounts for the largest share and growth of this foreign-based R&D activity. Indeed, drug companies accounted for almost 30 percent of total 1993 overseas R&D ($9.8 billion), which was equivalent to 17 percent of the pharmaceutical industry's domestically financed R&D. (See figure 4-24.) Of other major R&D-performing manufacturers, recent trends (since 1990) show the overseas R&D investment share of total R&D financing rising considerably for scientific instruments, but declining for machinery and electrical equipment. In each of these cases, however, the funding

Figure 4-24.
U.S. overseas R&D as a share of company-financed domestic R&D, by industry



See appendix table 4-40. *Science & Engineering Indicators – 1996*

shifts primarily reflect changes in industry classification of major R&D-performing firms rather than actual reductions in total overseas R&D.

Similarly, the combined total for all nonmanufacturing industries shows substantial increases in foreign R&D activity since 1985, rising from 0.4 to 7.0 percent in 1993. Part of this growth is indicative of increased international R&D financing by firms historically classified as nonmanufacturing industries (particularly computer, data processing, and architectural services). Part of the increase reflects the movement of firms previously classified as manufacturers (for example, office computing companies) to service sector industries (for example, software development).

Most of the U.S. overseas R&D is undertaken in Europe. As indicated by Bureau of Economic Analysis (BEA) data on majority-owned foreign affiliates of nonbank U.S. multinational companies, most of this 1993 R&D total was performed in Europe—primarily Germany (23 percent of the U.S. overseas total), the United Kingdom (15 percent), France (9 percent), and Ireland (6 percent). Collectively, however, the current 70-percent European share of the U.S. total R&D investment abroad is considerably less than the 76-percent share reported as recently as 1991. Since the early 1980s the U.S. R&D investment abroad has shifted more

[49]Companies consider several factors before undertaking R&D overseas: market access and accommodation of local requirements are but two of these factors. Tax and regulatory policies, as well as the availability of trained researchers and access to new scientific and technological developments in other countries, also influence R&D location decisions.

generally away from Europe and Canada and toward Japan and other Asian countries. These shifts reflect, in part, an appreciation for, and a desire to take advantage of, the increase in S&T strengths underway in Asia.[50] (See figure 4-25.)

By affiliate industry classification, more than one-half of the 1993 German-based R&D was performed by transportation equipment companies. In the United Kingdom and France, the chemicals industry accounted for the largest share of each countries' respective totals, whereas in Ireland, the machinery industry performed most of this U.S.-funded R&D. Canada accounted for 9 percent of U.S. companies' 1993 R&D performed abroad, and Japan—which receives comparatively small amounts of foreign R&D funds—accounted for 8 percent.[51] (See text table 4-10 and appendix table 4-41.) Notably, the U.S. R&D investment in Asian countries other than Japan has grown substantially. U.S. R&D spending in Singapore (primarily in machinery industries) and Indonesia (mostly for petroleum-related research) now surpasses that in many European nations.

Foreign Research and Development in the United States

Since at least 1981, the percentage of industry R&D expenditures financed from foreign sources has risen considerably in each of the seven largest R&D-performing countries, except Japan.[52] Foreign R&D accounts for an estimated 12 to 18 percent of industry's 1992 total in France, the United Kingdom, and Canada and for 3 to 6 percent of industry funds in Italy and Germany. According to OECD data (1995) on the 12 nations that compose the European Community,[53] the combined share of their industries' R&D performance that is foreign controlled has risen by more than one-half, from less than 5 percent in 1981 to more than 7 percent in 1992. The foreign component of Japan's domestic industrial R&D performance has held steady during the 1981–93 period at only about 0.1 percent. (See figure 4-26, and the section on Research and Development Funding by Source and Performer.)

Like U.S. firms' overseas R&D funding trends, R&D activity by foreign-owned companies in the United States has increased significantly since the early 1980s. From 1980 to 1993, inflation-adjusted R&D growth from foreign firms (U.S. affiliates with a foreign parent that owns 10 percent or more of the voting equity) averaged 12 percent per year, or more than three times the rate of growth in domestic R&D activities by U.S. companies (3.9 percent).[54] Using a more restrictive definition of foreign

[50]For example, see chapter 6, Technology Development and Competitiveness, and reports on the recent growth in the indigenous S&T capacities of several Asian countries (SRS, 1993; 1995c).

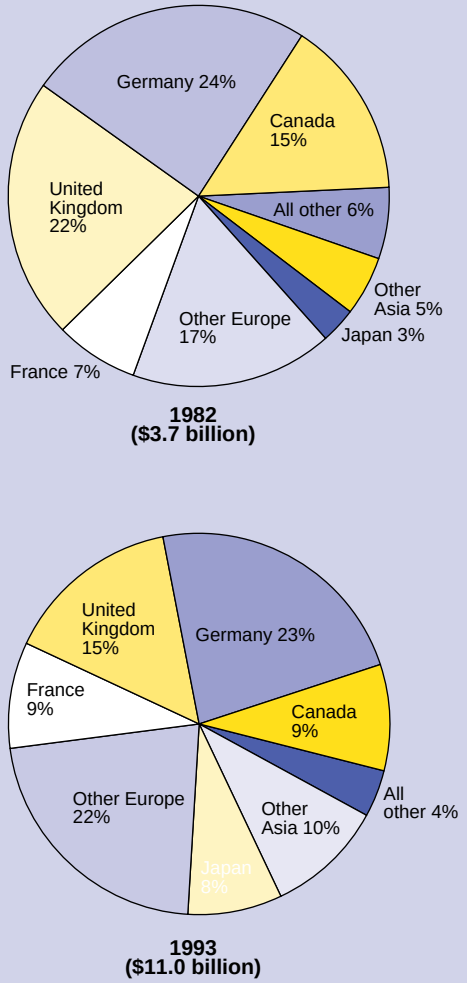
[51]These overseas R&D country shares are from the BEA survey on U.S. Direct Investment Abroad, not the NSF data series from which industry-specific shares are taken. The definition used by BEA for R&D expenditures is from the Financial Accounting Standards Board Statement No. 2; these expenditures include all charges for R&D performed for the benefit of the affiliate by the affiliate itself and by others on contract. BEA detail are available for 1982, and annually since 1989. NSF reports a 1993 overseas R&D total of $9.8 billion; BEA estimates overseas R&D expenditures by U.S. companies and their foreign affiliates at $11.0 billion.

[52]For countries other than the United States, the data in this section are taken from OECD (1995). The foreign-sourced R&D data for the United States come from an annual survey of Foreign Direct Investment in the United States conducted by BEA. BEA reports that the foreign R&D totals are comparable with the U.S. R&D business data published by NSF. Industry-specific comparisons, however, are limited because of differences in the industry classifications used by the two surveys (Quijano, 1990).

[53]These countries are Belgium, Denmark, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, and the United Kingdom. See also OECD (1995) for a discussion of international R&D investment trends.

[54]BEA considers all of an investment (including R&D) to be foreign if 10 percent or more of the investing U.S.-incorporated firm is foreign owned. (See appendix table 4-38.) Special tabulations were prepared by BEA to reveal R&D expenditures in the United States of those firms in which there is majority foreign ownership—i.e., 50 percent or more. For 1993, the 10-percent foreign ownership threshold results in an esti-

Figure 4-25.
U.S. R&D performed abroad



See appendix table 4-41.

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Text table 4-10.
R&D performed overseas for majority-owned foreign affiliates of U.S. parent companies, by selected country and industry of affiliate: 1993

Country	All industries	Manufacturing total	Chemicals	Machinery	Electrical equipment	Transportation equipment	Nonmanufacturing
	Millions of dollars						
Total	10,954	9,173	2,829	1,791	782	2,496	1,781
Canada	1,030	841	224	D	76	226	189
Europe	7,550	6,621	2,040	1,080	496	2,105	929
Belgium	460	370	329	5	5	8	90
France	942	781	518	49	41	27	161
Germany	2,568	2,429	329	219	143	1,428	139
Ireland	669	D	D	574	D	0	D
Italy	304	260	135	17	D	D	44
Netherlands	392	D	63	6	D	4	D
Spain	321	313	D	3	33	D	8
United Kingdom	1,639	1,409	543	183	46	383	230
Asia and Pacific	1,943	1,340	450	450	180	61	603
Japan	862	682	361	62	123	6	180
Australia	176	157	49	14	10	D	19
Singapore	312	291	D	264	14	0	21
Western hemisphere	384	333	103	D	13	103	51
Brazil	220	216	45	26	6	93	4
Middle East	29	23	2	3	17	0	6
Africa	18	15	9	2	0	1	3

D = withheld to avoid disclosing operations of individual companies

NOTES: Includes foreign direct investments of nonbank U.S. affiliates only. Includes R&D expenditures conducted by and for the foreign affiliates. Excludes expenditures for R&D conducted for others under a contract. Expenditures differ from those reported from NSF in appendix table 4-41.

SOURCE: U.S. Bureau of Economic Analysis (BEA), *U.S. Direct Investment Abroad* (Washington, DC: BEA, ongoing series).

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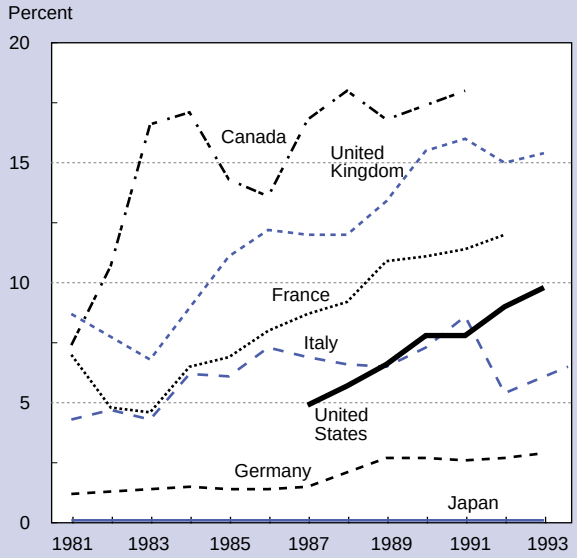
ownership in which the foreign parent owns 50 percent or more of the voting equity makes little difference in the aggregate trends. U.S.-performed R&D by such firms grew on average by about 12 percent annually from 1980 through 1993. (See figure 4-26.)

Much of this foreign R&D growth occurred since the mid-1980s, just as U.S. firms' domestic R&D investments were beginning to slow. As a result, foreign R&D was equivalent to 12 percent ($14.6 billion) of total industrial R&D performance in the United States in 1993—or double that of its equivalent 6-percent share in 1985. Majority-owned affiliates accounted for 10 percent ($11.6 billion) of the U.S. 1993 industrial performance total. Alternatively, as a percentage of total foreign and U.S. firms' industrial R&D funding, foreign companies accounted for 15 percent in 1993 (majority-owned affiliates accounted for 12 percent) compared with 9 percent in 1985. Although the R&D flows from Canada and other European countries also increased steadily over the past decade, 80 percent of this foreign funding came from five countries—Japan, Switzerland, the United Kingdom, Germany, and France. Swiss and Japanese firms increased their R&D investment in the United States more rapidly than did companies from the other nations. At

mated $14.6 billion foreign R&D investment total. R&D expenditures of majority-owned U.S. affiliates of foreign companies were $11.6 billion. (See appendix table 4-40.)

Figure 4-26.
Share of industry domestic R&D performance financed from foreign sources, by country



NOTES: For United States, foreign expenditures are from companies with at least 50 percent foreign ownership.

See appendix table 4-39. *Science & Engineering Indicators – 1996*

U.S. Research Facilities of Foreign Firms

The rapid growth in foreign R&D expenditures in the United States has been accompanied by a burgeoning establishment of R&D facilities here by foreign companies. According to a 1992 survey of 255 foreign-owned free-standing R&D facilities in the United States, about one-half had been established during the previous 6 years (Dalton and Serapio, 1993).* In a recent update to this study (Dalton and Serapio, forthcoming), the authors characterize the activities of 635 U.S. R&D facilities of more than 300 European, Japanese, and other foreign companies. Significant findings of this study follow:

- R&D facilities of Japanese firms outnumber those of all other countries. Japanese companies owned 219 R&D facilities in the United States; British companies owned 109; German companies owned 95 facilities; and French companies owned 52 facilities. South Korean companies owned 26 facilities in 1994. (See text table 4-11.)
- The activities of these foreign facilities were highly concentrated in the biotechnology (111 facilities), chemicals and rubber (109), automotive (53), and computer software (41), computer (39), and semiconductor (35) industries.
- Foreign R&D facilities were heavily concentrated in selected areas of the country, notably California's Silicon Valley and greater Los Angeles; Detroit; Boston; Princeton, NJ; and North Carolina's Research Triangle Park.
- The most important reasons cited for Japanese foreign R&D investment in the United States were to acquire technology, to keep abreast of technological developments, and to assist the parent company in meeting U.S. customer needs.
- Most of the basic research conducted by foreign companies in the United States is in pharmaceuticals and biotechnology.

*These counts are for only those facilities (R&D center, R&D company, or R&D laboratory) that are 50 percent or more owned by a foreign parent company. An R&D facility typically operates under its own budget and is located in a free-standing structure outside of and separate from the other U.S. facilities (e.g., sales and manufacturing facilities) of the parent. This definition of an R&D facility consequently excludes R&D departments or sections within U.S. affiliates of foreign-owned companies.

Text table 4-11.
U.S. R&D facilities of foreign companies, by selected industry and country: 1994

Industry	Total	Japan	United Kingdom	Germany	France	Switzerland	South Korea	Netherlands	Sweden	Other
	Millions of dollars									
Total	635	219	109	95	52	45	26	26	22	41
Computers	39	22	0	4	0	0	7	3	0	3
Software	41	25	6	4	3	0	1	1	0	1
Semiconductors	35	19	0	3	0	0	10	3	0	0
Telecommunications	29	14	2	4	2	1	1	0	2	3
Opto-electronics	20	11	2	3	0	0	0	0	1	3
HDTV, other electronics	71	33	10	9	4	5	3	4	0	3
Drugs, biotechnology	111	22	23	18	11	17	1	5	5	9
Chemicals, rubber, materials	109	23	19	28	17	10	0	4	0	8
Metals	15	5	3	1	4	1	0	0	1	0
Automotive	53	34	1	11	2	0	3	0	2	0
Machinery	22	7	4	2	3	0	0	0	6	0
Instrumentation, controls	40	1	23	3	5	4	0	3	1	0
Foods, consumer goods, misc	53	7	19	6	2	6	0	5	1	7

NOTE: Sum of industry detail may not add to country totals because of cross-industry R&D at facilities.

SOURCE: D.H. Dalton and M.G. Sherapio, Jr., *U.S. Research Facilities of Foreign Companies* (Washington, DC: Department of Commerce, Technology Administration/Japan Technology Program, 1995).

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Text table 4-12.
R&D performed in the U.S. by affiliates of foreign companies, by selected country and industry of affiliate: 1993

Country	All industy	Manufacturing						Service industries[1]
		Total	Drugs and medicines	Other chemicals	Machinery	Electrical equipment	Instruments	
	Millions of dollars							
Total	14,618	12,008	3,843	2,782	1,017	2,262	613	1,110
Europe	9,671	8,173	3,192	1,674	472	1,359	553	614
France	1,204	1,135	337	A	511	B	46	45
Germany	2,321	2,147	1,168	A	134	560	124	2
Netherlands	691	459	269	A	D	D	D	17
Switzerland	2,524	2,107	1,640	27	219	B	D	D
United Kingdom	2,295	1,944	D	D	53	93	216	132
Canada	2,190	2,084	D	D	12	D	8	D
Asia and Pacific	1,972	1,237	52	D	513	D	51	299
Japan	1,781	1,121	46	84	486	228	36	293
Latin America	635	454	D	D	15	3	1	D
Middle East	39	D	D	0	2	3	*	2

A = funds included with "Drugs and medicines"; B = funds included with "Machinery"; D = withheld to avoid disclosing operations of individual companies; * = less than $500,000

NOTES: Includes foreign direct investments of nonbank U.S. affiliates only. Includes R&D expenditures conducted by and for the foreign affiliates. Excludes expenditures for R&D conducted for others under a contract. Expenditures differ from those reported from NSF in appendix table 4-40.

[1]Includes computer and data processing services ($477 million) and accounting, research, and management services ($546 million).

SOURCE: U.S. Bureau of Economic Analysis, *Foreign Direct Investment in the United States: Operations of U.S. Affiliates of Foreign Companies*, unpublished preliminary tabulations.

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least part of the significant expansion of these foreign R&D expenditures in the United States is attributable to several major acquisitions by foreign multinational companies of U.S. firms, particularly of U.S. pharmaceutical and biotechnology firms with large R&D budgets. (See *U.S. Research Facilities of Foreign Firms* and text table 4-11.)

Foreign-funded research was concentrated in three industries in 1993—industrial chemicals (funded predominantly by German and Canadian firms), drugs and medicines (mostly from Swiss and British firms), and electrical equipment (one-third of which came from German and Japanese affiliates). These three industries accounted for three-fifths of the $14.6 billion total 1993 foreign R&D investment. Concurrent with gains reported for all domestic U.S. R&D performance, foreign—particularly Japanese—R&D investment in the service sector has also risen considerably. These industries accounted for 8 percent of the 1993 foreign R&D investment total, with most research being funded in computer, data processing, and research and management services. (See text table 4-12 and appendix tables 4-42 and 4-43.)

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