Chapter 4
Research and Development: Funds and Technology Linkages

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Highlights

National R&D Trends

U.S. R&D declined for the first time in almost 50 years in 2002 as a result of cutbacks in business R&D, but it has since recovered due to growth in all sectors of the economy.

- ♦ U.S. R&D grew to $291.9 billion in 2003 after declining in 2002 for the first time since 1953. U.S. R&D is projected to increase further to $312.1 billion in 2004.
- ♦ The business sector's share of U.S. R&D peaked in 2000 at 75%, but following the stock market decline and subsequent economic slowdown of 2001 and 2002, the business activities of many R&D-performing firms were curtailed. The business sector is projected to have performed 70% of U.S. R&D in 2004.

The decades-long trend of federal R&D funding shrinking as a share of the nation's total R&D reversed after 2000.

- ♦ The federal share of R&D funding first fell below 50% in 1979 and dropped to a low of 24.9% in 2000.
- ♦ The federal share of R&D funding grew to a projected 29.9% in 2004 as private investment slowed and federal spending on R&D expanded, particularly in the areas of defense, health, and counterterrorism.

U.S. R&D is dominated by development, largely performed by the business sector, with most basic research conducted at universities and colleges.

- ♦ In 2004 the United States performed an estimated $58.4 billion of basic research, $66.4 billion of applied research, and $187.3 billion of development.
- ♦ Universities and colleges have historically been the largest performers of basic research in the United States, and in recent years they have accounted for over half (55% in 2004) of the nation's basic research. Most basic research is federally funded.
- ♦ The development of new and improved goods, services, and processes is dominated by industry, which performed 90.2% of all U.S. development in 2004.

Location of R&D Performance

R&D is geographically concentrated, and states vary significantly in terms of the types of research performed within their borders.

- ♦ In 2003, the top 10 states in terms of R&D accounted for almost two-thirds of U.S. R&D. California alone accounted for more than one-fifth of the $278 billion of R&D that could be attributed to one of the 50 states or the District of Columbia.
- ♦ Federal R&D accounts for 86% of all R&D in New Mexico, the location of the two largest federally funded research and development centers (FFRDCs) in terms of R&D performance, Los Alamos National Laboratory and Sandia National Laboratories.
- ♦ Over half of all R&D performed in the United States by computer and electronic products manufacturers is located in California, Massachusetts, and Texas.
- ♦ The R&D of chemicals manufacturing companies is particularly prominent in two states, accounting for 61% of New Jersey's and 49% of Pennsylvania's business R&D. Together these two states represent almost one-third of the nation's R&D in this sector.

Business R&D

Business sector R&D is projected to have rebounded from its 2002 decline to a new high in 2004.

- ♦ R&D performed by the business sector is estimated to have reached $219.2 billion in 2004.
- ♦ The average R&D intensity of companies performing R&D in the United States peaked in 2001 at 3.8%, as R&D budgets remained steady despite a decline in sales of R&D-performing companies. R&D intensity declined to 3.2% in 2003 as a result of the 2002 decline in company R&D and stronger sales growth in 2003.
- ♦ Computer and electronic products manufacturers and computer-related services companies, combined, performed over one-third of all company-funded research and development in 2003.

Federal R&D

The current level of federal investment in R&D, both in absolute terms and as a share of the budget, is over an order of magnitude greater than what it was prior to World War II.

- ♦ In the president's 2006 budget submission, the federal government is slated to set aside $132.3 billion for R&D, amounting to 13.6% of its discretionary budget.
- ♦ Federal agencies are expected to obligate $106.5 billion for R&D support in FY 2005. The five largest R&D-funding agencies account for 94% of total federal R&D.

Defense-related R&D dominates the federal R&D portfolio.

- ♦ The largest R&D budget function in the FY 2006 budget is defense, with a proposed budget authority of $74.8 billion, or 59% of the entire federal R&D budget.
- ♦ In FY 2006, the Department of Defense (DOD) requested research, development, testing, and evaluation budgets in excess of $1 billion for four weapon systems.

Federal R&E Tax Credit

From 1990 to 2001, research and experimentation (R&E) tax credit claims by companies in the United States grew twice as fast as industry-funded R&D, after adjusting for inflation, but growth in credit claims varied throughout the decade.

- R&E tax credit claims reached an estimated $6.4 billion in 2001.
- From 1990 to 1996, companies claimed between $1.5 billion and $2.5 billion in R&E credits annually; since then, annual R&E credits have exceeded $4 billion. However, in 2001 R&E tax credit claims still accounted for less than 4% of industry-funded R&D expenditures.

Technology Linkages: Contract R&D, Public-Private Partnerships, and Industrial Alliances

Since 1993 R&D expenses paid to other domestic R&D performers outside their companies have increased as a proportion of company-funded R&D performed within firms.

- In 2003, companies in the United States reported $10.2 billion in R&D expenses paid to other domestic R&D performers outside their companies, compared with $183.3 billion in company-funded R&D performed within firms. The ratio of contracted-out R&D to in-house R&D was 5.6% for the aggregate of all industries in 2003, compared with 3.7% in 1993.

Participation by federal laboratories in cooperative research and development agreements (CRADAs) increased in FY 2003 but was still below the mid-1990s peak.

- Federal laboratories participated in a total of 2,936 CRADAs with industrial companies and other organizations in FY 2003, up 4.3% from a year earlier, but still below the 3,500 peak in FY 1996.

U.S. companies continue to partner with other American and international companies worldwide to develop and exploit new technologies.

- New industrial technology alliances worldwide reached an all-time peak in 2003 with 695 alliances, according to the Cooperative Agreements and Technology Indicators database. Alliances involving only U.S.-owned companies have represented the largest share of alliances in most years since 1980, followed by alliances between U.S. and European companies.

International R&D

R&D is performed and funded primarily by a small number of developed nations.

- In 2000, global R&D expenditures totaled at least $729 billion, half of which was accounted for by the two largest countries in terms of R&D performance, the United States and Japan.
- The R&D performance of Organisation for Economic Co-operation and Development (OECD) countries grew to $652 billion in 2002. The G-7 countries (Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States) performed over 83% of OECD R&D in 2002.
- More money was spent on R&D activities in the United States in 2002 than in the rest of the G-7 countries combined.

R&D intensity indicators, such as R&D/gross domestic product (GDP) ratios, also show the developed, wealthy economies well ahead of lesser-developed economies.

- Overall, the United States ranked fifth among OECD countries in terms of reported R&D/GDP ratios. Israel (not an OECD member country), devoting 4.9% of its GDP to R&D, led all countries, followed by Sweden (4.3%), Finland (3.5%), Japan (3.1%), and Iceland (3.1%).
- In the United States, the slowdown in GDP growth in 2001 preceded the decline of U.S. R&D in 2002. This resulted in U.S. R&D to GDP ratios of 2.7% in 2001 (a recent high) and 2.6% in 2002. Following the 2002 decline, R&D grew more rapidly than GDP in the United States, resulting in an R&D to GDP ratio of 2.7% in 2003.[1] The U.S. economy expanded at a faster pace in 2004, and R&D as a proportion of GDP remained at 2.7%.
- Although China and Germany reported similar R&D expenditures in 2000, on a per capita basis, Germany's R&D was over 16 times that of China.

R&D Investments by Multinational Corporations

U.S. multinational corporations (MNCs) continued to expand R&D activity overseas. However, the level of R&D expenditures by foreign MNCs in the United States has been even larger in recent years.

- In 2002, R&D expenditures by affiliates of foreign companies in the United States reached $27.5 billion, up 2.3% from 2001 after adjusting for inflation. By comparison, total U.S. industrial R&D performance declined by 5.6%, after adjusting for inflation, over the same period. On the other hand, foreign affiliates of U.S. MNCs performed $21.2 billion in R&D expenditures abroad in 2002, up 5.6% from 2001, after adjusting for inflation.

Cross-country R&D investments through MNCs continue to be strong between U.S. and European companies. At the same time, certain developing or newly industrialized economies are emerging as significant hosts of U.S.-owned R&D, including China, Israel, and Singapore.

- In 1994, major developed economies or regions accounted for 90% of overseas R&D expenditures by U.S. MNCs. This share decreased to 80% by 2001. The change reflects modest expenditures growth in European locations, compared with larger increases in Asia (outside Japan) and Israel.

Introduction

Chapter Overview

In 2006 the United States commemorates the bicentennial of Meriwether Lewis and William Clark's completed expedition of discovery across a then-uncharted North American continent. This expedition, championed by President Thomas Jefferson and funded by a federal appropriation of $2,500 in 1803, foreshadowed future voyages of discovery in the realms of science and technology (S&T) unimaginable two centuries ago. The commemoration of this expedition is recognition of the importance of scientific discovery to the nation and to the world.

The research and development activities undertaken today possess many of the same characteristics demonstrated by the Lewis and Clark expedition. Commerce, Jefferson's primary justification for the expedition, remains a driving force in discovery, and today profit-seeking firms perform most of the nation's R&D. At the same time, just as Congress did in 1803, governments still recognize that, for a variety of reasons, the private sector cannot or will not fund all of the R&D that might benefit society, and, therefore, public financing maintains an important role in the global R&D enterprise. And in our own time, modern R&D projects still require the teamwork and collaboration exhibited by Lewis and Clark's Corps of Discovery to advance the frontier of S&T.

Observing the trends in R&D and innovation, economist Jacob Schmookler (1962) concluded that, "The historical shifts in inventive attention appear to reflect the interplay of advancing knowledge, which opens up new inventive opportunities for exploitation, and the unfolding economic needs and opportunities arising out of a changing social order." These two forces—advancing scientific and technological knowledge and economic demand—can be characterized, respectively, as the supply and the demand sides of invention. Under this framework, advances in S&T may occur when the cost of invention (a function of current scientific knowledge) drops below the profit potential of invention (a function of demand). Similarly, shifts in demand for technological advances can raise the profit potential of invention above the cost of invention.

Technology developments resulting in part from national defense and other government investments in the first half of the 20th century, coupled with the growth of research universities and specialized industrial laboratories in advanced countries, cemented the role of S&T as a key contributor to national economic growth, productivity, security, and social welfare. In the second half of the 20th century, industrial innovation became increasingly globalized following international investments by multinational corporations (MNCs). Global R&D and related international investments are still concentrated in a few developed countries or regions. However, certain developing economies have increased their national R&D expenditures and have become hosts of R&D by U.S. MNCs within the past decade. Concurrent with these developments, industrial R&D is often performed in collaboration with external partners and contractors, assisted by an increasing international pool of scientific discoveries and talent.

Policymakers in both the public and private sectors constantly seek to evaluate their organizations' performance as a benchmark against both historical trends and current and future competitors. But because it is difficult to measure these advances directly, policymakers often use data on R&D expenditures as a proxy measure for the effort expended to make these advances possible. R&D expenditures indicate both the relative importance of advancing S&T compared with other goals as well as the perceived value of future S&T innovations. For example, R&D must compete for funding with other activities supported by discretionary government spending—from education to national defense. The resulting share of a government's budget that is devoted to R&D activities thus indicates governmental and societal commitment to R&D relative to other government programs. Likewise, profit-seeking firms invest in product R&D to the extent that they foresee a potential market demand for new and improved goods and services. Other indicators discussed in this chapter include industrial technology alliances and federal technology transfer activities.

Chapter Organization

This chapter is organized into seven sections that examine trends in R&D expenditures and collaborative technology activities. The first section provides an overview of national trends in R&D performance and R&D funding. The second analyzes data on the location of R&D performance in the United States. The third and fourth sections focus on the respective roles of business enterprises and the federal government in the R&D enterprise.

The fifth section summarizes available information on external technology sourcing and collaborative R&D activities across R&D-performing sectors, including industrial contract R&D expenditures, federal technology transfer, and domestic and international technology alliances.

The sixth section compares R&D trends across nations. It contains sections on total and nondefense R&D spending; ratios of R&D to gross domestic product (GDP) in various nations; international R&D funding by performer and source (including information on industrial subsectors and academic science and engineering fields); the allocation of R&D efforts among components (basic research, applied research, and development); and international comparisons of government R&D priorities and tax policies.

The seventh section presents data on R&D by U.S. MNCs and their overseas affiliates and by affiliates of foreign companies in the United States. Data include R&D expenditures by investing or host countries and their industrial focus, and R&D employment.

National R&D Trends

U.S. R&D grew to $291.9 billion in 2003 after declining in 2002 for the first time since 1953, when these data were first collected (see sidebar "Definitions of R&D").[2] The National Science Foundation (NSF) projects that U.S. R&D will continue to increase to $312.1 billion in 2004.

Definitions of R&D

R&D. According to international guidelines for conducting research and development surveys, R&D, also called research and experimental development, comprises creative work "undertaken on a systematic basis to increase the stock of knowledge—including knowledge of man, culture, and society—and the use of this stock of knowledge to devise new applications" (OECD 2002b, p. 30).

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 performed in fields of present or potential commercial interest.

Applied research. The objective of applied research is to gain the knowledge or understanding to meet a specific, recognized need. In industry, applied research includes investigations to discover 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.

R&D plant. R&D plant includes the acquisition of, construction of, major repairs to, or alterations in structures, works, equipment, facilities, or land for use in R&D activities.

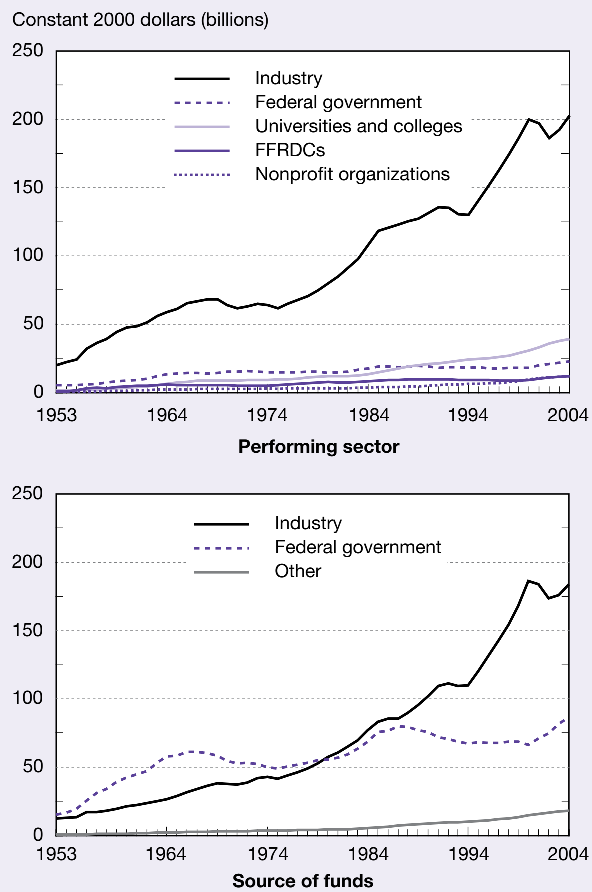
Budget authority. Budget authority is the authority provided by federal law to incur financial obligations that will result in outlays.

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

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

As a point of reference, in 1990 total U.S. R&D was $152.0 billion—less than half the projected figure for 2004. After adjusting for inflation, total R&D declined 2.2% between 2001 and 2002, then increased 3.9% in 2003 and increased a projected 4.7% in 2004.[3] These recent growth rates in R&D exceed the average annual growth rate over the prior two decades, but they do not match the 6% per year inflation-adjusted growth of the late 1990s that resulted from substantial increases in company R&D, most notably in information and communications technology (ICT) industries and in small R&D-performing firms (figure 4-1).[4] These official U.S. R&D data are derived by adding up the R&D performance for all sectors of the economy for which it can be reasonably estimated. For a description of the R&D activity not captured in these data, see sidebar "Unmeasured R&D."

Figure 4-1
National R&D, by performing sector and source of funds, 1953–2004



FFRDC = federally funded research and development center

SOURCE: National Science Foundation, Division of Science Resources Statistics, *National Patterns of R&D Resources* (annual series). See appendix tables 4-3 and 4-4.

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Unmeasured R&D

The estimates of U.S. R&D presented in this volume are derived from surveys of establishments that have historically performed the vast majority of R&D in the United States. However, to evaluate U.S. R&D performance over time and in comparison with other countries, it is necessary to gauge how much R&D is going unmeasured in the United States. The following are indicators of unmeasured R&D performance in the United States:

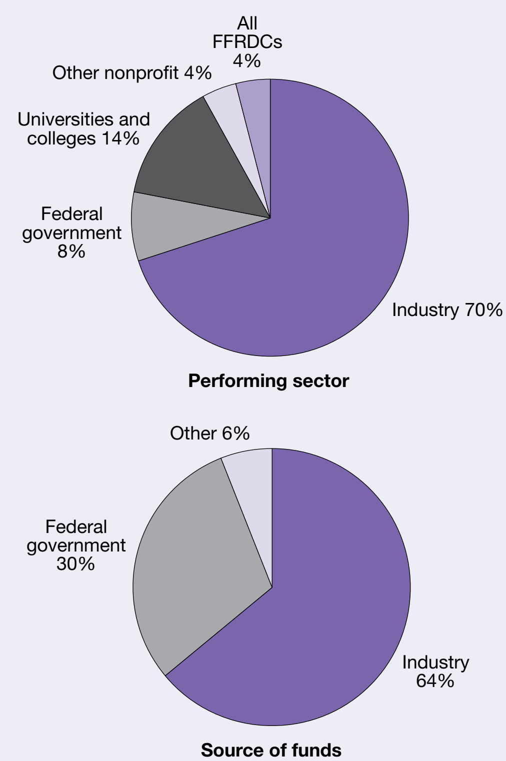
- To reduce cost and respondent burden, U.S. industrial R&D estimates are derived from a survey of R&D-performing companies with five or more employees. There are no estimates of R&D performance for companies with fewer than five employees; however, the 2004 census business registry classifies over 6,000 such companies in the scientific R&D services industry and almost 4,000 in the software industry.
- The activity of individuals performing R&D on their own time (and not under the auspices of a corporation, university, or other organization) is similarly not included in official U.S. R&D statistics. However, the U.S. Patent and Trademark Office reports that historically over 13% of U.S. patents for invention have been granted to U.S. individuals (http://www.uspto.gov/web/offices/ac/ido/oeip/taf/all_tech.htm#parta1_2b).
- The National Science Foundation (NSF) Survey of Research and Development Expenditures at Universities and Colleges collects data on "organized research," which includes sponsored projects as well as any separately budgeted research activity. However, no official estimates exist for the amount of academic departmental research, small projects, and general scholarly work performed without external funding. Scientists and engineers who do not receive a research grant often continue their research on a smaller scale as departmental research. Due to lack of resources, approximately 2,000 highly rated grant proposals were declined by NSF in FY 2004.
- Non-science and engineering R&D is excluded from U.S. industrial R&D statistics, and R&D in the humanities is excluded from U.S. academic R&D statistics. Other countries include both in their national statistics, making their national R&D expenditures relatively larger when compared with those of the United States.
- R&D performed by state and local governments in the United States is not currently surveyed or estimated for national statistics. A survey conducted in 1998 estimates that state agencies performed over $400 million of R&D in FY 1995 (http://www.nsf.gov/statistics/nsf99348/).
- Although NSF estimates the R&D performance of nonprofit organizations, a nonprofit R&D survey has not been fielded since 1998.

R&D Performance

The decline in 2002 and subsequent recovery of U.S. R&D can largely be attributed to the business sector, which performed 70% of U.S. R&D in 2004 (figure 4-2). The next largest sector in terms of R&D performance—universities and colleges—performs one-fifth the R&D of businesses. However, universities and colleges perform over half of the nation's basic research (table 4-1) (see the discussion of R&D by character of work that appears later in this chapter). Federal agencies and all federally funded research and development centers (FFRDCs) combined performed 12% of U.S. total R&D in 2004.[5] Federal R&D is discussed in more detail later in this chapter.

From 2000 to 2004, U.S. R&D increased by 2% per year in real terms. The business sector's share of U.S. R&D peaked in 2000 at 75%, but following the stock market decline and subsequent economic slowdown of 2001 and 2002, the business activities of many R&D-performing firms were curtailed. As a result, business R&D grew by only 0.3% per year in real terms between 2000 and 2004. During this period more robust growth was evident at federal agencies and FFRDCS, where R&D performance increased by 6.5% per year in real terms,

Figure 4-2
Shares of national R&D expenditures, by performing sector and source of funds: 2004



FFRDC = federally funded research and development center

NOTES: Values rounded to nearest whole number. National R&D expenditures estimated at $312 billion in 2004.

SOURCE: National Science Foundation, Division of Science Resources Statistics, *National Patterns of R&D Resources* (annual series). See appendix tables 4-3 and 4-5.

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and at universities and colleges, where R&D performance increased by 6.3% per year in real terms.[6]

R&D Funding

Besides performing the majority of U.S. R&D, the business sector is also the largest source of R&D funding in the United States and provided 64% ($199 billion) of total R&D funding in 2004 (figure 4-2). Most businesses spend their R&D budgets on either internal R&D projects or for contract R&D performed by other businesses (see section on contract R&D). Only 1.7% of business R&D funding flows to other sectors. The federal government provided the second largest share of R&D funding, 30% ($93.4 billion). Unlike in the business sector, the majority of federal R&D dollars finance R&D in other sectors, with only 40.3% of these funds financing federal agencies and FFRDCs. The other sectors of the economy (e.g., state governments, universities and colleges, and nonprofit institutions) contributed the remaining 6% ($20 billion) (table 4-1; see also sidebar "Alternative Methods for Stimulating R&D: Prizes as R&D Incentives").

Table 4-1
U.S. R&D expenditures, by character of work, performing sector, and source of funds: 2004

Performing sector	Source of funds ($ millions)					Total expenditures (% distribution)
	Total	Industry	Federal government	U&C	Other nonprofit institutions	
R&D	312,068	199,025	93,384	11,095	8,565	100.0
Industry	219,226	195,691	23,535	NA	NA	70.2
Industry-administered FFRDCs	2,584	NA	2,584	NA	NA	0.8
Federal government	24,742	NA	24,742	NA	NA	7.9
U&C	42,431	2,135	26,115	11,095	3,087	13.6
U&C-administered FFRDCs	7,500	NA	7,500	NA	NA	2.4
Other nonprofit institutions	12,750	1,199	6,072	NA	5,478	4.1
Nonprofit-administered FFRDCs	2,834	NA	2,834	NA	NA	0.9
Percent distribution by source	100.0	63.8	29.9	3.6	2.7	NA
Basic research	58,356	9,551	36,075	7,579	5,150	100.0
Industry	9,278	7,427	1,851	NA	NA	15.9
Industry-administered FFRDCs	706	NA	706	NA	NA	1.2
Federal government	4,887	NA	4,887	NA	NA	8.4
U&C	31,735	1,458	20,589	7,579	2,109	54.4
U&C-administered FFRDCs	3,917	NA	3,917	NA	NA	6.7
Other nonprofit institutions	6,651	666	2,944	NA	3,042	11.4
Nonprofit-administered FFRDCs	1,181	NA	1,181	NA	NA	2.0
Percent distribution by source	100.0	16.4	61.8	13.0	8.8	NA
Applied research	66,364	35,975	25,315	2,883	2,190	100.0
Industry	41,009	35,117	5,892	NA	NA	61.8
Industry-administered FFRDCs	1,268	NA	1,268	NA	NA	1.9
Federal government	8,407	NA	8,407	NA	NA	12.7
U&C	9,223	555	4,983	2,883	802	13.9
U&C-administered FFRDCs	1,806	NA	1,806	NA	NA	2.7
Other nonprofit institutions	4,287	304	2,595	NA	1,388	6.5
Nonprofit-administered FFRDCs	365	NA	365	NA	NA	0.5
Percent distribution by source	100.0	54.2	38.1	4.3	3.3	NA
Development	187,349	153,498	31,993	633	1,224	100.0
Industry	168,939	153,147	15,792	NA	NA	90.2
Industry-administered FFRDCs	610	NA	610	NA	NA	0.3
Federal government	11,447	NA	11,447	NA	NA	6.1
U&C	1,474	122	543	633	176	0.8
U&C-administered FFRDCs	1,778	NA	1,778	NA	NA	0.9
Other nonprofit institutions	1,812	229	534	NA	1,048	1.0
Nonprofit-administered FFRDCs	1,288	NA	1,288	NA	NA	0.7
Percent distribution by source	100.0	81.9	17.1	0.3	0.7	NA

NA = not available

FFRDC = federally funded research and development center; U&C = universities and colleges

NOTES: State and local government support to industry included in industry support for industry performance. State and local government support to U&C ($2,890 million in total R&D) included in U&C support for U&C performance.

SOURCES: National Science Foundation, Division of Science Resources Statistics, *National Patterns of R&D Resources* (annual series). See appendix tables 4-3, 4-7, 4-11, and 4-15.

Science and Engineering Indicators 2006

Federal R&D Funding

The federal government was once the foremost sponsor of the nation's R&D, funding as much as 66.8% of all U.S. R&D in 1964 (figure 4-3). The federal share first fell below 50% in 1979 and dropped to a low of 24.9% in 2000. The declining share of federal R&D funding is most evident in the business sector. In the late 1950s and early 1960s over half of the nation's business R&D was funded by the federal government, but by 2000 less than 10% of business R&D was federally funded.[7] The decades-long trend of federal R&D funding shrinking as a share of the nation's total R&D reversed after 2000. As private investment slowed, federal spending on R&D expanded, particularly in the areas of defense, health, and counterterrorism. These changing conditions resulted in a growing federal share of R&D funding, projected at 29.9% in 2004.

Nonfederal R&D Funding

R&D funding from nonfederal sources is projected to have reached $218.7 billion in 2004. After adjusting for inflation, nonfederal R&D funding was only 0.7% higher in 2004 than in 2000. Business sector funding dominates nonfederal R&D support. Of the total 2004 nonfederal R&D support, 91% ($199 billion) was company funded. The business sector's share of national R&D funding first surpassed the federal government's share in 1980. From 1980 to 1985, industrial support for R&D, in real dollars, grew at an average annual rate of 7.8%. This growth was maintained

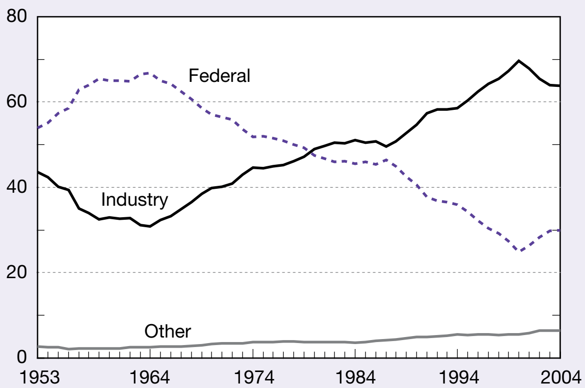
Alternative Methods for Stimulating R&D: Prizes as R&D Incentives

Uncertainty is a defining characteristic of research and development. At the outset of an R&D project, there is no guarantee of technical success. Given this uncertainty, investments of time and money into R&D "are not likely to be forthcoming in volume without commensurate prospective rewards in income or prestige" (Schmookler 1962). In some cases, even when technical success is virtually guaranteed, the lack of a perceived profitable market or of well-defined property rights for an invention stymies investment in R&D. In many cases where market incentives are insufficient to motivate private sector R&D investment, governments and other nonprofit organizations directly fund R&D through grants, contracts, and cooperative agreements.

A less common approach to stimulate R&D is to create a market for the results of R&D where none existed. This can be achieved by either offering a prize for achieving some technical goal or by making credible promises to purchase products resulting from the R&D. These methods have been used for centuries to foster innovation. Prominent examples of prizes and market-based incentives for R&D include:

- The series of prizes offered in 1714 by the British government to the person who could develop an accurate technique for measuring longitude. John Harrison, after 40 years of work, won the top prize of 20,000 pounds for his chronometer, H4.
- A prize of 12,000 francs offered in 1795 by Napolean's Society for the Encouragement of Industry for a method of food preservation usable by the French military. The prize was awarded in 1810 for a process that sterilized food sealed in champagne bottles.
- The $10 million Ansari X PRIZE for the first private manned spacecraft to exceed an altitude of 100 km twice in as many weeks. Mojave Aerospace led by Burt Rutan and Paul Allen won the prize on 4 October 2004 with its spacecraft, SpaceShipOne. The resulting media publicity likely outweighed the prize money, as the X PRIZE became the number two news story of 2004. (http://www.xprizefoundation.com/news/default.asp)
- The Methuselah Mouse Prize (MPrize) for the scientific research team that develops the longest living *Mus musculus,* the breed of mouse most commonly used in scientific research. The goal of this prize is to encourage research into the potential for near-term science-based aging interventions. (http://www.methuselahmouse.org/)
- InnoCentive, founded in 2001 by Eli Lilly and Company, an online incentive-based initiative for R&D. Using the website, a firm can anonymously post a research problem along with a bounty and a deadline for responses. As of 2005, there were 75,000 registered scientists from more than 165 countries registered with InnoCentive. If a scientist can provide a solution that meets the firm's specified criteria, that person will collect the bounty. (www.innocentive.com)
- Project BioShield, signed into law by President Bush on 21 July 2004, creates a guaranteed market for next-generation vaccines and drugs to protect Americans from the threat of bioterrorism. The law provides the Department of Homeland Security with $5.6 billion over 10 years for the purchase of next generation countermeasures against anthrax and smallpox as well as other biological or chemical agents. (http://www.whitehouse.gov/bioshield/)
- The National Aeronautics and Space Administration's (NASA's) Centennial Challenges Program offers a number of monetary prizes to stimulate innovation and competition in solar system exploration and other NASA mission areas. (http://exploration.nasa.gov/centennialchallenge/cc_index.html)

Figure 4-3
National R&D expenditures, by source of funds: 1953–2004



SOURCE: National Science Foundation, Division of Science Resources Statistics, *National Patterns of R&D Resources* (annual series). See appendix table 4-5.

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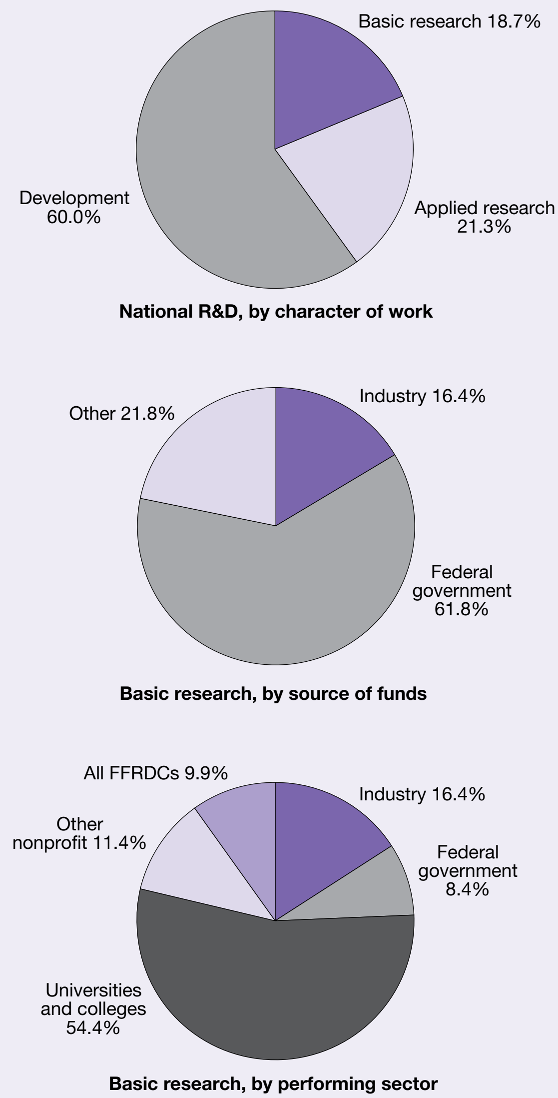
through both the mild 1980 recession and the more severe 1982 recession (figure 4-1). Between 1985 and 1994, growth in R&D funding from industry was slower, averaging only 3.1% per year in real terms, but from 1994 to 2000, industrial R&D support grew in real terms by 9.2% per year. This rapid growth rate came to a halt following the downturn in both the market valuation and economic demand for new technology in the first years of the 21st century. Between 2000 and 2002, industrial R&D support declined by 3.4% per year in real terms, but it subsequently grew at inflation-adjusted rates of 1.4% in 2003 and 4.5% in 2004.

Although R&D funding from other nonfederal sectors (namely, academic and other nonprofit institutions and state and local governments) is small in comparison to federal and business R&D spending, it has grown rapidly. In the 20 years between 1984 and 2004, funding from these sectors grew at an average annual rate of 6.4%, twice as fast as R&D funding from the federal and business sectors combined. Most of these funds went to research performed within the academic sector.

R&D by Character of Work

Because R&D encompasses a broad range of activities, it is helpful to disaggregate R&D expenditures into the categories of basic research, applied research, and development. Despite the difficulties in classifying specific R&D projects, these categories are useful for characterizing the expected time horizons, outputs, and types of investments associated with R&D expenditures. In 2004 the United States performed an estimated $58.4 billion of basic research, $66.4 billion of applied research, and $187.3 billion of development (table 4-1). As a share of all 2004 R&D expenditures, basic research represented 18.7%, applied research represented 21.3%, and development represented 60.0% (figure 4-4).

Figure 4-4
National R&D by character of work, basic research by source of funds, and basic research by performing sector: 2004



FFRDC = federally funded research and development center

NOTES: Figures rounded to nearest whole number. National R&D expenditures estimated at $313 billion in 2004.

SOURCE: National Science Foundation, Division of Science Resources Statistics, *National Patterns of R&D Resources* (annual series). See appendix tables 4-3, 4-7, 4-11, and 4-15.

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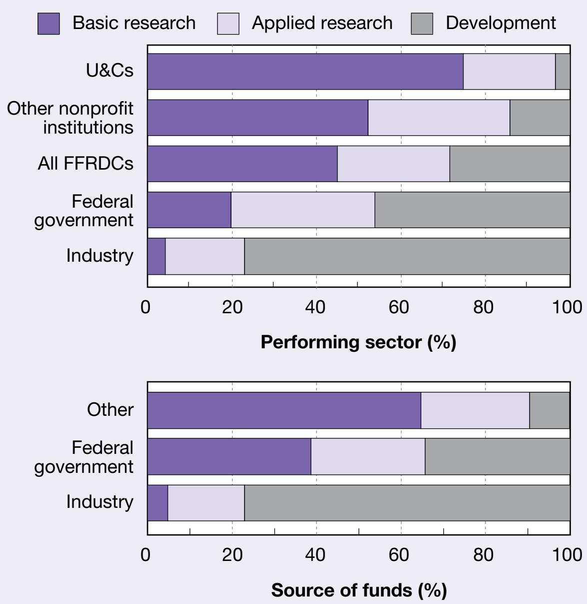
Basic Research

Universities and colleges have historically been the largest performer of basic research in the United States, and in recent years they have accounted for more than half (55% in 2004) of the nation's basic research (table 4-1). Organizations influence the type of R&D conducted by their scientists and engineers both directly and indirectly. The most direct influence is the decision to fund specific R&D projects. This influence tends to be weaker in academia than in industry or government agencies because academic researchers generally have more freedom to seek outside R&D funding. This reliance on external sources of funding, along with the tenure system, makes universities and colleges well suited to carrying out basic research (particularly undirected basic research).

The federal government, estimated to have funded 61.8% of U.S. basic research in 2004, has historically been the primary source of support for basic research (figure 4-4). Moreover, the federal government funded 64.9% of the basic research performed by universities and colleges in 2004. Industry devoted only an estimated 4.8% of its total R&D support to basic research in that year (figure 4-5), representing 16% of the national total. The reasons for industry's relatively small contribution to basic research are that this activity generally involves a high degree of risk in terms of technical success and the potential commercial value of any discovery, as well as concern about the ability of the firm to enforce property rights over the discovery. However, firms may have other reasons for performing basic research in addition to immediate commercial demands. For example, a company that supports basic research could boost its human capital (by attracting and retaining academically motivated scientists and engineers) and strengthen its innovative capacity (i.e., its ability to absorb external scientific and technological knowledge). The industries that invest the most in basic research are those whose new products are most directly tied to recent advances in S&E, such as the pharmaceuticals industry and the scientific R&D services industry.

Figure 4-5
R&D performing sectors and source of funds, by character of work: 2004



FFRDC = federally funded research and development center; U&C = universities and colleges

NOTES: State and local government support to industry is included in industry support for industry performance. State and local government support to U&C ($2,890 million in total R&D) is included in U&C support for U&C performance.

SOURCES: National Science Foundation, Division of Science Resources Statistics, *National Patterns of R&D Resources* (annual series). See appendix tables 4-3, 4-7, 4-11, and 4-15.

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Applied Research

The business sector spends over three times as much on applied research than on basic research and accounts for about half of U.S. applied research funding. In 2004 the federal government invested $25.3 billion in applied research funding, 38.1% of the U.S. total. Whereas most of the federal investment in basic research supports work done at universities and colleges, the majority of federally funded applied research is performed by federal agencies and FFRDCs. Historically, the federal government's investment has emphasized basic research over applied research, reflecting the belief that the private sector is less likely to invest in basic research. In 2004, the federal government spent 43% more on basic research funding than on applied research funding (figure 4-5).

Within industry, applied research refines and adapts existing scientific knowledge and technology into knowledge and techniques useful for creating or improving products, processes, and services. The level of applied research in an industry reflects both the market demand for substantially (as opposed to cosmetically) new and improved goods and services, as well as the level of effort required to transition from basic research to technically and economically feasible concepts. Examples of industries that perform a relatively large amount of applied research are the chemicals industry, the aerospace industry (largely financed by the Department of Defense [DOD]), and the R&D services industry (encompassing many biotechnology companies).

Development

Development expenditures totaled an estimated $187.3 billion in 2004, representing the majority of U.S. R&D expenditures. The development of new and improved goods, services, and processes is dominated by industry, which performed 90.2% of all U.S. development in 2004. Universities, colleges, and other nonprofit institutions account for less than 2% of U.S. development performance. The balance of development is performed by federal agencies and FFRDCs, representing 8% of the U.S. total in 2004.

Industry and the federal government together funded 99% of all development in 2004, with industry providing 82% and the federal government providing 17%. Most federal development spending is defense related. The federal government generally invests in the development of such products as military aircraft and space exploration vehicles, for which it is the only consumer. Other typologies can be used to analyze R&D. One alternative is used in the federal budget as discussed in the section entitled "Federal S&T Budget" within "Federal R&D Funding by National Objective" appearing later in this chapter.

Location of R&D Performance

R&D performance is geographically concentrated in the United States. Over 50% of U.S. R&D is performed in only seven states.[8] Although R&D expenditures are concentrated in relatively few states, patterns of R&D activity vary considerably among the top R&D-performing locations (appendix tables 4-23 and 4-24). (For a broader range of indicators of state-level S&E activities, see chapter 8.)

Distribution of R&D Expenditures Among States

In 2003 the 20 highest-ranking states in R&D expenditures accounted for 84% of U.S. R&D expenditures, whereas the 20 lowest-ranking states accounted for 6%. The top 10 states accounted for almost two-thirds of U.S. R&D expenditures in 2003 (table 4-2). California alone accounted for more than one-fifth of the $278 billion U.S. R&D total, exceeding the next highest state by a factor of three.[9] Figure 4-6, a cartogram of the United States with states sized in proportion to the amount of R&D performed within them, illustrates the geographic concentration of U.S. R&D along both coasts and in the Great Lakes region.

States vary significantly in the size of their economies because of differences in population, land area, infrastructure, natural resources, and history. Consequently, state variations in R&D expenditure levels may simply reflect differences in economic size or the nature of R&D efforts. One way to control for the size of each state's economy is to measure each state's R&D level as a percentage of its gross state product (GSP).[10] Like the ratio of national R&D to GDP discussed later in this chapter, the proportion of a state's GSP devoted to R&D is an indicator of R&D intensity. Some of the states with the highest R&D to GSP ratios include Michigan, home to the major auto manufacturers; Massachusetts, home to a number of large research universities and a thriving high-technology industry; and Maryland, home to the National Institutes of Health (NIH). A list of states and corresponding R&D intensities can be found in appendix table 4-24.

Sector Distribution of R&D Performance by State

Although leading states in total R&D tend to be well represented in each of the major R&D-performing sectors, the proportion of R&D performed in each of these sectors varies across states. Because business sector R&D accounts for 71% of the distributed U.S. total, it is not surprising that 9 of the top 10 states in terms of total R&D performance are also in the top 10 in terms of industry R&D (table 4-2). University-performed R&D accounts for only 14% of the U.S. total, but it is also highly correlated with the total R&D performance in a state.

There is less of a relationship between federal R&D performance (both intramural and FFRDC) and total R&D, as federal R&D is more geographically concentrated than the R&D performed by other sectors.[11] Figure 4-7, a cartogram of the United States with states sized in proportion to federal R&D performance in the state, illustrates that the top four states in terms of federal R&D (California, New Mexico, Maryland, and Virginia), along with the District of Columbia, account for over half (56%) of all federal R&D performance. Federal R&D accounts for 86% of all R&D in New Mexico, the location of the two largest FFRDCs in terms of R&D performance, Los Alamos National Laboratory and Sandia National Laboratories. Federal R&D accounts for 41% of all R&D performed in Maryland, Virginia, and the District of Columbia, reflecting the concentration of federal facilities and administrative offices within the national capital area.

Table 4-2
Top 10 states in R&D performance, by sector and intensity: 2003

			Sector ranking			R&D intensity (R&D/GSP ratio)		
Rank	State	Total R&D[a] (current $ millions)	Industry	U&C	Federal intramural and FFRDC[b]	State	R&D/GSP (%)	GSP (current $ billions)
1	California	59,664	California	California	California	New Mexico	8.72	57.1
2	Michigan	16,884	Michigan	New York	New Mexico	Massachusetts	5.26	297.1
3	Massachusetts	15,638	New Jersey	Texas	Maryland	Maryland	4.77	213.1
4	Texas	14,785	Massachusetts	Maryland	Virginia	Michigan	4.70	359.4
5	New York	13,031	Texas	Pennsylvania	District of Columbia	Washington	4.68	245.1
6	New Jersey	12,795	Washington	Massachusetts	Massachusetts	Rhode Island	4.46	39.4
7	Washington	11,469	New York	Illinois	Washington	California	4.15	1,438.1
8	Illinois	11,045	Illinois	North Carolina	Illinois	District of Columbia	3.80	70.7
9	Maryland	10,162	Pennsylvania	Michigan	New York	Connecticut	3.76	174.1
10	Pennsylvania	9,944	Ohio	Ohio	Alabama	New Hampshire	3.45	48.2

FFRDC = federally funded research and development center; GSP = gross state product; U&C = universities and colleges

[a]Includes in-state total R&D performance of industry, universities, federal agencies, FFRDCs, and federally financed nonprofit R&D.
[b]Includes costs associated with administration of intramural and extramural programs by federal personnel and actual intramural R&D performance.

NOTES: Rankings do not account for margin of error of estimates from sample surveys.

SOURCES: National Science Foundation, Division of Science Resources Statistics, *National Patterns of R&D Resources* (annual series); and U.S. Bureau of Economic Analysis, U.S. Department of Commerce (2005), http://www.bea.gov/bea/newsrel/gspnewsrelease.htm.

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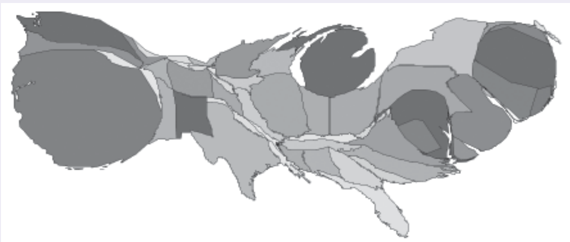
Figure 4-6
R&D expenditures and R&D/gross state product ratios, by state: 2003



NOTES: States sized relative to their R&D in 2003. Darker shading indicates higher R&D/GSP ratio (R&D intensity).

SOURCE: National Science Foundation, Division of Science Resources Statistics, *National Patterns of R&D Resources* (annual series). See appendix tables 4-23 and 4-24.

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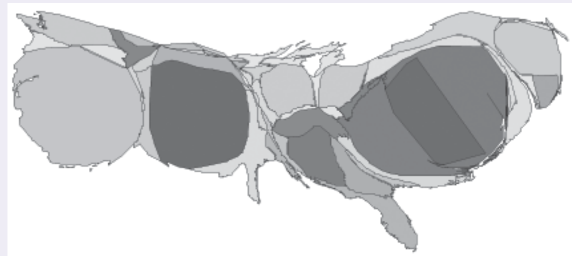
Figure 4-7
Federal intramural and FFRDC R&D expenditures, by state: 2003



FFRDC = federally funded research and development center

NOTES: States sized relative to their federal intramural and FFRDC R&D in 2003. Darker shading indicates federal R&D represents larger share of state's total R&D.

SOURCE: National Science Foundation, Division of Science Resources Statistics, *National Patterns of R&D Resources* (annual series). See appendix tables 4-23.

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Federal R&D also represents 37% of the R&D performed in Alabama, due largely to DOD's Redstone Arsenal laboratories and the National Aeronautics and Space Administration's (NASA's) George C. Marshall Space Flight Center, both in Huntsville. Looking across all states, federal R&D represents only 12% of the distributed U.S. total.

Industrial R&D in Top States

The types of companies that carry out R&D vary considerably among the 10 leading states in industry-performed R&D (table 4-3). This reflects regional specialization or clusters of industrial activity. For example, in Michigan the motor vehicles industry accounted for 70% of industrial R&D in 2003, whereas it accounted for only 8% of the nation's total industrial R&D. In Washington, companies performing computer-related services (such as software development) dominate, accounting for over 50% of the state's business-sector R&D. These companies accounted for 13% of the nation's business R&D in 2003.

The computer and electronic products manufacturing industries account for 24% of the nation's total industrial R&D, but they account for a larger share of the industrial R&D in California (33%), Massachusetts (47%), and Texas (46%). These three states have clearly defined regional centers of high-technology research and manufacturing: Silicon Valley in California, Route 128 in Massachusetts, and the Silicon Hills of Austin, Texas. Over half of all R&D performed in the United States by computer and electronic products companies is located in these three states.

The R&D of chemicals manufacturing companies is particularly prominent in New Jersey and Pennsylvania, both of which host robust pharmaceutical and chemical industries. These companies account for 61% of New Jersey's and 49% of Pennsylvania's business R&D. Together these two states represent almost one-third of the nation's R&D in this sector.

The R&D services sector is even more concentrated geographically, with California, Massachusetts, and Ohio accounting for nearly half of the nation's R&D in this sector. Companies in this sector, consisting largely of biotechnology companies, contract research organizations, and early-stage technology firms, maintain strong ties to the academic sector and often are located near large research universities. (See the section entitled "Technology Linkages: Contract R&D, Public-Private Partnerships, and Industrial Alliances" appearing later in this chapter.) The state of Ohio has been particularly aggressive in pursuing policies that support this sector. Ohio's $1.1 billion Third Frontier Project, initiated in 2002, commits $500 million over 10 years to fund new technology, biomedical research, and technology transfer, and more than $500 million to enhance research facilities.[12]

The R&D performance of small companies (defined as having from 5 to 499 employees) is also concentrated geographically.[13] Nationally, small companies perform 18% of the nation's total business R&D, but in California, Massachusetts, and New York these companies perform between 21% and 23% of the states' business R&D. About 40% of the R&D performed in the United States by companies in this category is performed in these three states.

Business R&D

Businesses perform R&D with a variety of objectives in mind, but most business R&D is aimed at developing new and improved goods, services, and processes. For most firms, R&D is a discretionary expense similar to advertising. R&D does not directly generate revenue in the same way that production expenses do, so it can be trimmed with little impact on revenue in the short term. Firms attempt to invest in R&D at a level that maximizes future profits while maintaining current market share and increasing operating efficiency. R&D expenditures therefore indicate the level of effort dedicated to producing future products and process

Table 4-3
Top 10 states in industry R&D performance and share of R&D, by selected industry: 2003
(Percent)

		Share of industry-performed R&D					
State	Industry-performed R&D (current $ millions)	Chemicals[a]	Computer and electronic products[b]	Computer-related services	R&D services	Motor vehicles	Companies with 5–499 employees
All states	204,004	15.9 L	23.9 L	13.4 L	8.6	8.3	17.6
California	47,142	7.0	33.1	18.7	13.7	5.0	21.4
Michigan	15,241	D	1.7	D	3.0	70.4	7.0
New Jersey	11,401	61.0	2.9	D	D	0.2	11.6
Massachusetts	11,094	8.3	47.3	11.8	13.4	0.2	23.4
Texas	11,057	4.5	45.7	9.7	6.5	0.6	17.4
Washington	9,222	D	D	D[c]	5.5	0.3	10.9
New York	8,556	30.0	23.6	7.0	7.9	3.2	22.2
Illinois	8,319	21.4	34.4	10.3	2.6	3.8	13.6
Pennsylvania	7,091	48.6	9.1	5.2	7.5	1.4	19.0
Ohio	6,260	10.6	4.6	5.4	9.7	D	16.4

D = data withheld to avoid disclosing operations of individual companies; L = lower bound estimate

[a]Includes R&D of drugs and druggists' sundries wholesale trade industry.
[b]Includes R&D of professional and commercial equipment and supplies, including computers wholesale trade industry.
[c]In 2002, computer-related services accounted for more than 50% of Washington's industry-performed R&D.

NOTES: Rankings do not account for margin of error of estimates from sample surveys. Detail does not add to total because not all industries are shown.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Industrial Research and Development (2003).

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improvements in the business sector; by extension, they may reflect firms' perceptions of the market's demand for new and improved technology.

As previously mentioned, R&D performed by private industry is estimated to have reached $219.2 billion in 2004. The federal government funded 10.7% ($23.5 billion) of this total, and company funds and other private sources financed the remainder. These estimates are derived from the NSF and the U.S. Census Bureau's annual Survey of Industrial Research and Development, which collects financial data related to R&D activities from companies performing R&D in the United States. These data provide a basis for analyzing the technological dynamism of the business sector and are the official source for U.S. business R&D estimates (see sidebar "Industry Classification Complicates Analysis").

In addition to absolute levels of R&D expenditures, another key S&T indicator in the business sector is R&D intensity, a measure of R&D relative to production in a company, industry, or sector. Many ways exist to measure R&D intensity; the one used most frequently is the ratio of company-funded R&D to net sales.[14] This statistic provides a way to gauge the relative importance of R&D across industries and among firms in the same industry. The average R&D intensity of companies performing R&D in the United States peaked in 2001 at 3.8% as R&D budgets remained steady despite a decline in sales of R&D-performing companies. R&D intensity declined to 3.2% in 2003 as a result of the 2002 decline in company R&D and strong sales growth in 2003.

Largest R&D Industries

Although all industries benefit from advances in S&T, industries perform different amounts of R&D.[15] Some industries have relatively low R&D intensities (0.5% or less), such as the utilities industry and the finance, insurance, and real estate industries (appendix table 4-22). Six groups of industries account for three-quarters of company funded business R&D and 95% of federally funded business R&D (table 4-4).

Computer and Electronic Products

The computer and electronic products manufacturing sector accounts for the largest amount of business R&D performed in the United States (table 4-4). Industries in this sector include companies that manufacture computers, computer peripherals, communications equipment, and similar electronic products, and companies that manufacture components for such products. The design and use of integrated circuits and the application of highly specialized miniaturization technologies are common elements in the production processes of the computer and electronic products sector.

In 2003, these industries performed at least $42.5 billion of R&D, or 21% of all business R&D.[17] Companies and other nonfederal sources funded almost all of this R&D. The focus of the R&D in this sector is on development, with less than 16% of company-funded R&D devoted to basic and applied research. Two of the more R&D-intensive industries—communications equipment and semiconductor manufacturing—are included in this group. Both devoted more than 11% of sales to R&D in 2003.

Industry Classification Complicates Analysis

Each company sampled in the Survey of Industrial Research and Development is assigned to a single industry based on payroll data for the company,[16] and each is requested to report its R&D expenditures for the entire company. These expenditures are assigned to the previously established single industry. This classification scheme reasonably categorizes most companies into industries closely aligned with their primary business activities. However, for diversified companies that perform R&D in support of a variety of industries, any single assigned industry is only partly correct. And in some cases, the industry assigned based on payroll data is not directly related to a company's R&D activities.

Given this classification scheme, interpretation of industry-level R&D data is not always straightforward. It is important to assess the relationships between industries as well as the business structure within industries when analyzing R&D data. For example, most of the federally funded R&D reported in the navigational, measuring, electromedical, and control instruments industry is performed by large defense contractors that also produce aerospace products. And investigations of survey microdata revealed that most of the R&D classified into the trade industry represents the activities of manufacturing firms that have integrated their supply chains and brought their warehousing, sales, and marketing efforts in house. For example, a large pharmaceutical firm could be classified in the trade industry if the payroll associated with its sales and marketing efforts outweighed that of its manufacturing activities. Therefore any analysis of the pharmaceutical industry's R&D should involve a concurrent analysis of the R&D reported in the drugs and druggists' sundries wholesalers industry. The same holds true for the computer and electronic products industries and their representative trade industry, professional and commercial equipment and supplies wholesalers. Wherever possible, this report aggregates industry-level data in a way that accounts for these classification issues.

Table 4-4
R&D and domestic net sales, by selected business sector: 2002 and 2003
(Current $ millions)

Sector	Total R&D		Federal R&D		Company R&D		Domestic net sales	
	2002	2003	2002	2003	2002	2003	2002	2003
All industries	190,809	203,853	16,401	22,108	174,408	181,745	4,903,345	5,809,394
Highlighted sectors	145,887 L	159,560 L	15,686 L	20,829 L	130,201	138,731	2,073,655	2,224,473
Automotive manufacturing	15,199 L	16,874 L	NA	NA	15,199	16,874	487,740	703,834
Chemicals	27,452 L	32,474 L	246 L	103 L	27,206	32,370	415,873	489,604
Computer/electronic products	42,367 L	39,871 L	289 L	61 L	42,078	39,810	526,577	450,528
Computer-related services	27,549 L	27,436 L	1,643 L	1,148 L	25,907	26,288	262,774	201,567
Aerospace/defense manufacturing	16,126 L	23,410 L	9,872	14,179	6,254 L	9,231 L	265,994 L	270,054 L
R&D services	17,193	19,497	3,636	5,338	13,557	14,158	114,697	108,886
All other industries	D	D	D	D	44,207	43,014	2,829,690	3,584,921

L = lower bound estimate; D = data withheld to avoid disclosing operations of individual companies; NA = not available; all federal R&D for transportation industries (including that of automotive manufacturing) included in aerospace/defense manufacturing sector.

NOTES: All federal R&D for navigational, measuring, electromedical, and control instruments industry included in aersospace/defense manufacting sector. All nonfederal R&D and domestic net sales for the navigational, measuring, electromedical, and control instruments industry included in computer/electronic products sector. Potential disclosure of individual company operations only allows lower bound estimates for federal R&D in the chemicals, computer/electronic products, and computer-related services sectors.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Industrial Research and Development (2003).

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Chemicals

The chemicals industry performed an estimated $32.5 billion of R&D in 2003. Like the computer and electronic products industries, very little of the R&D in the chemicals industry is federally funded. In terms of R&D performance, the largest industry within the chemicals subsector is pharmaceuticals and medicines. In 2003, pharmaceutical companies performed $25.4 billion of company-funded R&D, representing 79% of nonfederal R&D funding of the chemicals sector.

The Pharmaceutical Research and Manufacturers of America (PhRMA), an industry association that represents the country's leading research-based pharmaceutical and biotechnology companies, annually surveys its members for information on their R&D investments. In 2003, PhRMA members reported investing $27.1 billion domestically in R&D, of which 38% was for basic and applied research (PhRMA 2005).[18] Most of PhRMA members' domestic R&D investment supports continuing R&D on projects that originated in their own laboratories (73% in 2003), but 20% supports R&D on products licensed from other companies (notably biotechnology companies), universities, or the government. In NSF's Survey of Industrial Research and Development, companies that predominantly license their technology rather than manufacture finished products are often classified in the scientific R&D services industry. Therefore, a sizeable amount of biotechnology R&D that serves the pharmaceutical industry is reported in the R&D services sector (see section "R&D Services").

Computer-Related Services

Industries associated with software and computer-related services (such as data processing and systems design) performed approximately $26.1 billion of company-funded R&D in 2003.[19] The R&D of these industries combined with that of the computer and electronic products manufacturers discussed earlier account for over one-third of all company-funded R&D in 2003. As computing and information technology became more integrated with every sector of the economy, the demand for services associated with these technologies boomed. The R&D of companies providing these services also grew dramatically during this period. In 1987, when an upper bound estimate of software and other computer-related services R&D first became available, companies classified in the industry group "computer programming, data processing, other computer-related, engineering, architectural, and surveying services" performed $2.4 billion of company-funded R&D, or 3.8% of all company-funded industrial R&D. In 2003 the company-funded R&D of a comparable group of industries (excluding engineering and architectural services) accounted for 14.3% of all company-funded industrial R&D (table 4-5).[20] Although the R&D activities of computer-related services companies have grown dramatically, this group is not the sole performer of software development R&D in the United States. In fact, companies in almost every industry report expenditures for software development R&D.

Aerospace and Defense Manufacturing

Although it is common to refer to the "defense industry," there is no such category in the industry classification system used by the federal government. Companies performing the majority of DOD's extramural R&D are classified in the aerospace products and parts industry; other transportation equipment industries; and the navigational, measuring, electromedical, and control instruments manufacturing industry. In 2003 these industries reported performing $14.3 billion of federal R&D, accounting for 69% of all federal R&D expenditures reported by companies (table 4-4). Almost half of the $15.7 billion of R&D performed by companies classified in the aerospace industry in 2003 came from federal sources. (See the section on federal R&D later in this chapter for further discussion of defense R&D.)

R&D Services

Companies in the business of selling scientific and engineering R&D services to other companies or licensing the results of their R&D are generally classified in the architectural, engineering, and related services industry or the scientific R&D services industry. Companies in this sector perform the majority of the federal R&D that is not performed by aerospace and defense manufacturing firms, $3.8 billion in 2003. Despite the significant amount of government-sponsored R&D performed by this sector, R&D services companies increasingly rely on nonfederal sources of R&D financing. The R&D performed by companies in the R&D services sector and funded by company and other nonfederal sources has grown from $5.8 billion in 1997 to $13.8 billion in 2003, an increase of 138%.[21] By comparison,

Table 4-5
Estimated share of computer-related services in company-funded R&D and domestic net sales of R&D-performing companies: 1987–2003
(Percent)

Year	Company-funded R&D	Domestic net sales
1987	3.8	1.4
1988	3.6	1.5
1989	3.4	1.4
1990	3.7	1.5
1991	3.6	1.6
1992	4.0	1.6
1993	8.2	1.5
1994	6.6	2.2
1995	8.8	3.3
1996	8.8	2.6
1997	9.1	2.5
1998	9.5	2.2
1999	10.6	2.2
2000	10.9	2.8
2001	13.0	3.5
2002	14.6	5.4
2003	14.3	3.5

NOTES: Data before 1998 are for companies classified in Standard Industrial Classification (SIC) industries 737 (computer and data processing services) and 871 (engineering, architectural, and surveying services). For 1998 on, data are for companies classified in North American Industry Classification System (NAICS) industries 5112 (software), 51 minus (511, 513; other information), and 5415 (computer systems design and related services). With SIC classification, information technology services share of company-funded R&D is 10.4% for 1998, indicating that SIC-based data may overestimate information technology services R&D and net sales relative to NAICS-based data.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Industrial Research and Development, special tabulations (2005).

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the company-funded R&D of all other industries increased by 33% over the same period. Because much of the R&D reported by these companies also appears in their reported sales figures, the R&D intensity of the R&D services sector is particularly high (13% in 2003).

Although the companies in this sector and their R&D activities are classified as nonmanufacturing, many of the industries they serve are manufacturing industries. For example, many biotechnology companies in the R&D services sector license their technology to companies in the pharmaceutical manufacturing industry. If a research firm was a subsidiary of a manufacturing company rather than an independent contractor, its R&D would be classified as R&D in a manufacturing industry. Consequently, growth in R&D services may, in part, "reflect a more general pattern of industry's increasing reliance on outsourcing and contract R&D" (Jankowski 2001). (For more information, see the section entitled "Contract R&D Expenses.")

Automotive Manufacturing

The sixth largest business sector in terms of R&D is automotive manufacturing. Companies in this industry reported performing $16.9 billion of company-funded R&D in 2003, accounting for 9% of all such R&D performed by businesses in the United States. At one time, this industry played a larger role in U.S. business R&D, accounting for as much as 16.2% of all company-funded and -performed R&D in 1959.

In 2003, 13 companies in the automotive manufacturing industry reported R&D expenditures over $100 million, representing approximately 85% of the industry's R&D. In most industries large companies perform more R&D than small companies, but in the automotive manufacturing industry the distribution of R&D is even more skewed towards large companies, with the R&D activities of the "Big Three" auto manufacturers (General Motors, Ford, and DaimlerChrysler) dominating the sector. In their annual reports to shareholders, these companies reported combined total engineering, research, and development expenses of $15.8 billion in FY 2003 (see sidebars "R&D Expenses of Public Corporations" and "Trends in R&D for Industrial Research Institute Members").[22]

Federal R&D

In the president's 2006 budget submission, the federal government is slated to invest $132.3 billion in R&D, amounting to 13.6% of its discretionary budget (i.e., that part of the annual federal budget that the president proposes and Congress debates and sets). The current level of federal investment in R&D, both in absolute terms and as a share of the budget, is over an order of magnitude greater than what it was prior to World War II, when the government had no unified national agenda for supporting science. In its early days, the U.S. government fostered innovation primarily through intellectual property protection and relatively small investments in R&D, but World War II changed how the federal government viewed its role in the national R&D enterprise. During the war, penicillin, a new drug at the time, greatly reduced the number of deaths caused by infection among Allied forces. And advances in military research, such as radar, were critical contributors to the Allied victory. Recognizing these achievements, President Franklin D. Roosevelt wrote to Vannevar Bush, the wartime director of the Office of Scientific Research and Development, requesting recommendations for how science could be mobilized in times of peace as it was in times of war, specifically "for the improvement of the national health, the creation of new enterprises bringing new jobs, and the betterment of the national standard of living" (Roosevelt 1944). Vannevar Bush's response in 1945, a report entitled "Science—The Endless Frontier," provided a framework for a more active federal role in support of science. He argued that:

> There are areas of science in which the public interest is acute but which are likely to be cultivated inadequately if left without more support than will come from private sources. These areas—such as research on military problems, agriculture, housing, public health, certain medical research, and research involving expensive capital facilities beyond the capacity of private institutions—should be advanced by active Government support…[W]e are entering a period when science needs and deserves increased support from public funds. (Bush 1945)

Bush's report was enormously influential, and many of its principles, including the importance of government support for R&D and of maintaining freedom of scientific inquiry, are evident in today's federal science policy and institutions.

Richard Nelson (1959) and Kenneth Arrow (1962) formalized the economic argument that the private sector generally invests less than the socially optimal amount in R&D. Briefly, the argument is that knowledge, the primary output of R&D, is nonrival and partially nonexcludable. That is, knowledge can be used by any number of actors at one time, and it is difficult or impossible to exclude others from using it. This being the case, firms will only invest in those R&D projects from which, through secrecy, patents, or some other means, they are able to recoup their investment plus an acceptable profit. The government endeavors to correct this market failure through a number of policy measures, the most direct of which is the funding and performance of R&D that would not, or could not, be financed or performed in the private sector. This section presents data on such R&D funding and performance as well as on the federal R&D tax credit, an indirect means of stimulating R&D in the private sector.

R&D by Federal Agency

Federal agencies are expected to obligate $106.5 billion for R&D support in FY 2005. Although more than 25 agencies report R&D obligations, the 5 largest R&D-funding agencies account for 94% of total federal R&D. These agencies vary considerably in terms of their R&D funding

R&D Expenses of Public Corporations

Most firms that make significant investments in R&D track their R&D expenses separately in their accounting records and financial statements. The annual reports of public corporations often include data on these R&D expenses. In 2003 the 20 public corporations with the largest reported worldwide R&D expenses spent $103.8 billion on R&D. Microsoft topped the list with $7.8 billion in R&D expenses, followed by Ford Motor Company with $7.5 billion (table 4-6). Companies in the information and communications technologies (ICT) sector dominate this list, with nine representatives accounting for 44% of the total R&D expenses. The remaining 11 companies include 6 automobile manufacturers and 5 pharmaceutical manufacturers. The top 20 companies are headquartered in six different countries, with nine headquartered in the United States. However, the location of a company's headquarters is not necessarily the location of all its R&D activities. Most of the companies on this list have manufacturing and research facilities in multiple countries around the world. (For more information, see the section entitled "R&D Investments by Multinational Corporations.")

A recent change in accounting standards by the Financial Accounting Standards Board (FASB) will result in discontinuities in companies' reported R&D expenses, making it more difficult to evaluate R&D spending trends from publicly available financial data. By 2006 most large companies are expected to follow the guidelines of FASB's Statement of Financial Accounting Standards (SFAS) 123, *Accounting for Stock-Based Compensation,* which requires companies to expense the fair value of all stock-based compensation.[23] Many high-technology companies have historically compensated their R&D employees with stock options and stock awards. This stock-based compensation may not have been reported as company expenses prior to these new guidelines. The dramatic increase in Microsoft's R&D expenses from 2002 to 2003, resulting in its move from number 10 to number 1 on the list of global R&D companies, was the result of Microsoft's early implementation of SFAS 123 in July 2003.[24] Prior to that date, the value of stock options awarded to employees was not included in the reported expenses of the company. Accounting for the value of this compensation resulted in Microsoft restating its 2002 R&D expenses up by $1.9 billion. The company does not detail how much stock-based compensation contributes to its 2003 R&D expenses. Microsoft's R&D in table 4-6 is likely exaggerated relative to other companies because it was an early adopter of SFAS 123. (See sidebar "Trends in R&D for Industrial Research Institute Members" for information on how some U.S.-based corporations intended to adjust their R&D strategies in 2005.)

Table 4-6
Top 20 R&D-spending corporations: 2003

	R&D rank		R&D expense ($ millions)			Sales ($ millions)		R&D intensity (%)	
Company (country)	2003	2002	2003	2002	Change (%)	2003	2002	2003	2002
Microsoft[a] (United States)	1	10	7,779	6,595	17.0	36,835	32,187	21.1	20.5
Ford Motor (United States)	2	1	7,500	7,700	–2.6	164,196	162,586	4.6	4.7
Pfizer (United States)	3	6	7,131	5,176	37.8	45,188	32,373	15.8	16.0
DaimlerChrysler (Germany)	4	2	6,689	7,289	–8.2	163,811	179,595	4.1	4.1
Toyota Motor (Japan)	5	5	6,210	6,113	1.6	157,411	146,121	3.9	4.2
Siemens (Germany)	6	3	6,084	6,987	–12.9	89,127	100,873	6.8	6.9
General Motors (United States)	7	4	5,700	5,800	–1.7	183,244	184,214	3.1	3.1
Matsushita Electric Industrial (Japan)	8	9	5,272	5,015	5.1	68,078	67,368	7.7	7.4
International Business Machines (United States)	9	7	5,068	4,750	6.7	89,131	81,186	5.7	5.9
GlaxoSmithKline (United Kingdom)	10	8	4,910	5,101	–3.8	37,717	37,314	13.0	13.7
Johnson & Johnson (United States)	11	12	4,684	3,957	18.4	41,862	36,298	11.2	10.9
Sony (Japan)	12	14	4,683	4,033	16.1	68,230	68,023	6.9	5.9
Nokia (Finland)	13	22	4,514	3,664	23.2	35,365	36,038	12.8	10.2
Intel (United States)	14	11	4,360	4,034	8.1	30,141	26,764	14.5	15.1
Volkswagen (Germany)	15	25	4,233	3,471	22.0	104,639	104,393	4.0	3.3
Honda Motor (Japan)	16	15	4,086	3,976	2.8	74,293	72,554	5.5	5.5
Motorola (United States)	17	13	3,771	3,754	0.5	27,058	26,679	13.9	14.1
Novartis (Switzerland)	18	24	3,756	3,362	11.7	24,864	25,111	15.1	13.4
Roche Holding (Switzerland)	19	27	3,694	3,298	12.0	24,188	23,030	15.3	14.3
Hewlett-Packard (United States)	20	19	3,652	3,312	10.3	73,061	56,588	5.0	5.9

[a]Fiscal year ended June 2004.

SOURCE: Institute of Electronics and Electronics Engineers (IEEE), IEEE Spectrum Top 100 R&D Spenders, Standard & Poor's data (2004), http://www.spectrum.ieee.org/WEBONLY/publicfeature/nov04/1104rdt1.pdf.

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Trends in R&D for Industrial Research Institute Members

For over 20 years the Industrial Research Institute (IRI), a nonprofit association of more than 200 leading R&D-performing industrial companies, has surveyed its U.S.-based members on their intentions for the coming year with respect to R&D expenditures, focus of R&D, R&D personnel, and other items. Because IRI member companies carry out a large amount of industrial R&D in the United States, the results from these surveys help identify broad trends in corporate R&D strategies. The most recent survey, administered in late 2004, suggests that many companies are shifting the focus of their R&D spending from directed basic research and support of existing business to new business projects (IRI 2005). This reported shift in R&D priorities also is reflected in how responding companies intend to spend their R&D budgets. IRI survey respondents reported the following plans for 2005:

- Increase total company expenditures on R&D
- Increase hiring of new graduates
- Increase outsourcing of R&D to other companies
- Increase outsourcing for university R&D and federal laboratories
- Increase participation in alliances and joint R&D ventures

Overall, these strategic moves are consistent with responses suggesting increased R&D budgets following a period of relative austerity. Responding companies are increasing R&D spending to support existing lines of business as well as new business projects and are leveraging their R&D spending through joint R&D ventures and grants/contracts for university R&D. (For more information, see "Technology Linkages: Contract R&D, Public-Private Partnerships, and Industrial Alliances.")

strategies, processes, and procedures, reflecting the unique mission, history, and culture of each.

Department of Defense

According to preliminary data, DOD will obligate $51.4 billion for R&D support in FY 2005. DOD funds more R&D than any other federal agency, representing 48% of all federal R&D obligations. More than 88% of these funds ($45.7 billion) will be spent on development, with $39.6 billion slated for major systems development (figure 4-8).[25] Industrial firms are expected to perform 70.4% of DOD-funded R&D in FY 2005. DOD accounts for more than 84% of all federal R&D obligations to industry in FY 2005. Federal intramural R&D and R&D performed by FFRDCs account for most of DOD's remaining R&D activity and represent 25.7% of its fiscal year total. According to the Office of Management and Budget (OMB), 72% of DOD's basic and applied research funding was allocated using competitive merit review processes with internal (program) evaluations in 2005.[26]

Department of Health and Human Services

HHS, the primary source of federal health-related R&D funding (largely through the National Institutes of Health), will obligate the second largest amount for R&D in FY 2005 at $28.9 billion, representing 27% of all federal R&D obligations. In contrast to DOD, HHS will allocate most of its R&D funding ($15.2 billion) for basic research. In FY 2005, HHS is expected to provide universities and colleges, the primary recipients of HHS funding, with $16.0 billion, which represents 67% of all federal R&D funds obligated to universities and colleges (table 4-7). HHS will provide 74% ($4.4 billion) of all federal R&D funds obligated to nonprofit institutions. Most of these institutions are large research hospitals such as Massachusetts General Hospital and the Dana-Farber Cancer Institute (NSF/SRS 2002). In 2005, competitive merit review processes with external (peer) evaluations were used to allocate 86% of HHS's basic and applied research funding.

National Aeronautics and Space Administration

The third largest agency in terms of R&D support is NASA, with R&D obligations expected to total $8.1 billion in FY 2005. Over one-third ($2.9 billion) of NASA's R&D activity is in development, much of which relies on industrial performers similar to those funded by DOD. However, unlike the industrial R&D funded by DOD, the majority (69%) of that funded by NASA supports research projects (basic and applied) as opposed to development. NASA is also the primary sponsor of R&D projects at nine federal facilities (including the Ames Research Center in California's Silicon Valley and the Marshall Space Flight Center in Huntsville, Alabama) and one FFRDC, the Jet Propulsion Laboratory, administered by the California Institute of Technology.

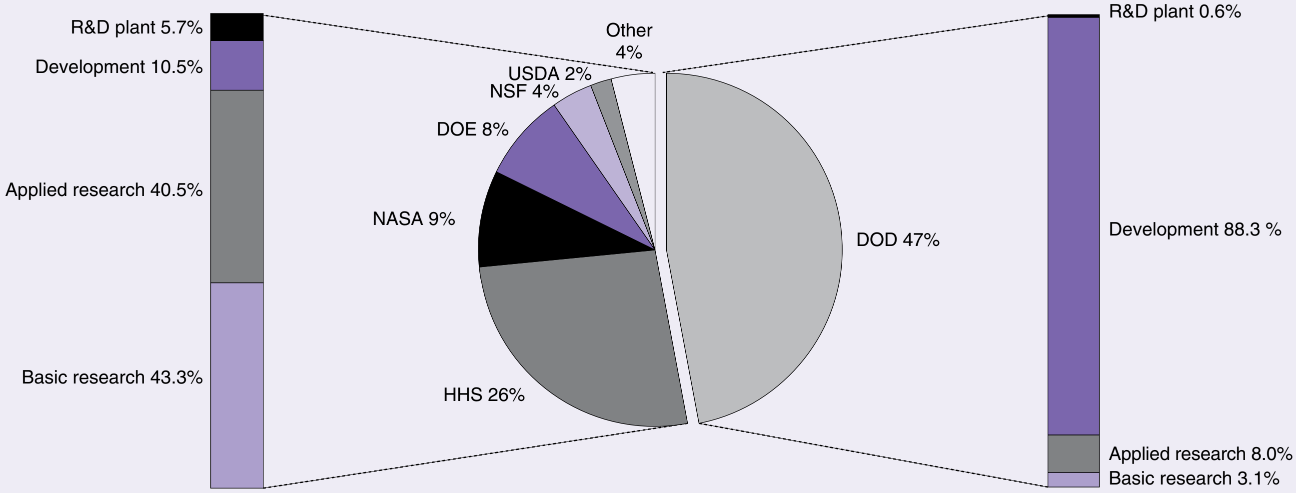
Department of Energy

Of the large R&D-funding agencies, the Department of Energy (DOE) relies the most on the R&D capabilities of FFRDCs. In FY 2005, DOE obligated 60% of its estimated $8 billion in R&D funding to FFRDCs. Of the 37 FFRDCs, DOE sponsored 16 and accounted for 59% of all federal R&D obligations to FFRDCs in FY 2005. Due to the scale and complexity of its research projects, most of DOE's research can only be performed in its intramural laboratories and FFRDCs. (See sidebar "Rationales for Federal Laboratories and FFRDCs.")

National Science Foundation

NSF is the federal government's primary source of funding for general S&E R&D and is expected to fund $3.8 billion of R&D in FY 2005. Of these funds, 94% are for basic research. NSF is the second largest federal source of R&D

Figure 4-8
Projected federal obligations for R&D and R&D plant, by agency and character of work: FY 2005



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

NOTE: Detail may not add to total because of rounding.

SOURCE: National Science Foundation, Division of Science Resources Statistics, *Federal Funds for Research and Development: Fiscal Years 2003, 2004, and 2005* (forthcoming). See appendix table 4-30.

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Rationales for Federal Laboratories and FFRDCs

- **Scale.** Some R&D efforts require capital expenditures, facilities, and staffing that exceed the capabilities or resources of private sector research organizations. Termed “big science,” this R&D is often compared to the Manhattan Project of World War II and today spans the spectrum of scientific exploration from high-energy physics (e.g., DOE’s Fermi National Accelerator Laboratory) to medicine (e.g., the National Cancer Institute at Frederick, located within Fort Detrick, a U.S. Army base in Frederick, Maryland) to astronomy (e.g., NSF’s National Astronomy and Ionosphere Center in Arecibo, Puerto Rico).
- **Security.** The sensitive nature of some R&D necessitates direct government supervision. Security has historically been a concern of defense-related R&D performed at Department of Defense (DOD) and Department of Energy (DOE) laboratories and federally funded research and development centers (FFRDCs). However, the growing focus on the threat of bioterrorism highlights that some nondefense R&D, such as that carried out by the Centers for Disease Control and Prevention, is also influenced by national security.
- **Mission and Regulatory Requirements.** Some federal agencies, such as the Department of Transportation and the Food and Drug Administration, must perform a certain amount of R&D to fulfill their missions. To ensure impartiality and fairness, this R&D is performed in federal laboratories.
- **Knowledge Management.** For logistical reasons, federal laboratories and FFRDCs are often tasked with performing long-term or mission-critical R&D. These organizations possess the institutional memory and close connection to the sponsoring agency required by these types of projects. An additional benefit of in-house expertise in R&D sponsoring agencies is the complementary role it plays in the management of extramural R&D programs.

Table 4-7
Estimated federal R&D obligations, by performing sector and agency funding source: FY 2005

Character of work and performer	Total obligations ($ millions)	Primary funding agency		Secondary funding agency	
		Agency	Percent	Agency	Percent
All federal government	106,487.8	DOD	48	HHS	27
Federal intramural	24,813.0	DOD	49	HHS	23
Industrial firms	42,938.0	DOD	84	NASA	7
Industry-administered FFRDCs	1,639.3	DOE	60	HHS	30
Universities and colleges FFRDCs	4,955.4	DOE	59	NASA	28
Other nonprofit organizations	5,971.5	HHS	74	NASA	10
Nonprofit-administered FFRDCs	1,463.9	DOE	58	DOD	38
Basic research	26,860.3	HHS	57	NSF	13
Federal intramural	5,106.5	HHS	50	DOD	16
Industrial firms	1,674.8	HHS	51	NASA	27
Industry-administered FFRDCs	342.2	HHS	79	DOE	19
Universities and colleges	13,924.5	HHS	64	NSF	22
Universities and colleges FFRDCs	1,985.0	DOE	61	NASA	25
Other nonprofit organizations	2,920.6	HHS	83	NSF	8
Nonprofit-administered FFRDCs	655.1	DOE	93	DOD	4
Applied research	27,837.7	HHS	49	DOD	15
Federal intramural	8,175.9	HHS	39	DOD	17
Industrial firms	5,012.0	DOD	40	NASA	32
Industry-administered FFRDCs	890.6	DOE	72	HHS	24
Universities and colleges	9,070.0	HHS	79	DOD	5
Universities and colleges FFRDCs	1,533.3	DOE	90	NASA	4
Other nonprofit organizations	2,599.4	HHS	75	NASA	8
Nonprofit-administered FFRDCs	190.7	DOE	58	DOD	23
Development	51,788.7	DOD	88	NASA	6
Federal intramural	11,529.7	DOD	87	NASA	6
Industrial firms	36,251.0	DOD	94	DOE	3
Industry-administered FFRDCs	406.5	DOE	71	DOD	29
Universities and colleges	905.8	DOD	58	NASA	18
Universities and colleges FFRDCs	1,437.1	NASA	59	DOE	22
Other nonprofit organizations	451.5	NASA	47	DOD	25
Nonprofit-administered FFRDCs	618.0	DOD	78	DOE	21

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

NOTE: Subtotal by performer may not add to total because state and local governments and foreign performers of R&D not detailed.

SOURCE: NSF, Division of Science Resources Statistics, *Federal Funds for Research and Development: Fiscal Years 2003, 2004, and 2005* (forthcoming).

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funds to universities and colleges; $3.2 billion is slated for academic researchers in FY 2005. In 2005, 73% of NSF's basic and applied research funding was allocated using competitive merit review processes with external (peer) evaluations. Most of its remaining research funding was allocated using competitive merit review processes with internal (program) evaluations.

Other Agencies

DOD, HHS, NASA, DOE, and NSF are expected to account for 94.1% of all federal R&D obligations in FY 2005 and slightly higher shares of federal obligations for basic research (94.5%) and development (98.8%). The remaining federal R&D obligations come from a variety of mission-oriented agencies such as the Department of Agriculture (USDA), the Department of Commerce (DOC), and the Department of the Interior (DOI). Unlike the larger R&D-funding agencies, USDA, DOC, and DOI direct most of their R&D funds to their own laboratories, which are run by the Agricultural Research Service, the National Institute for Standards and Technology (NIST), and the U.S. Geological Survey, respectively.

Federally Funded R&D by Performer

Federal Funding to Academia

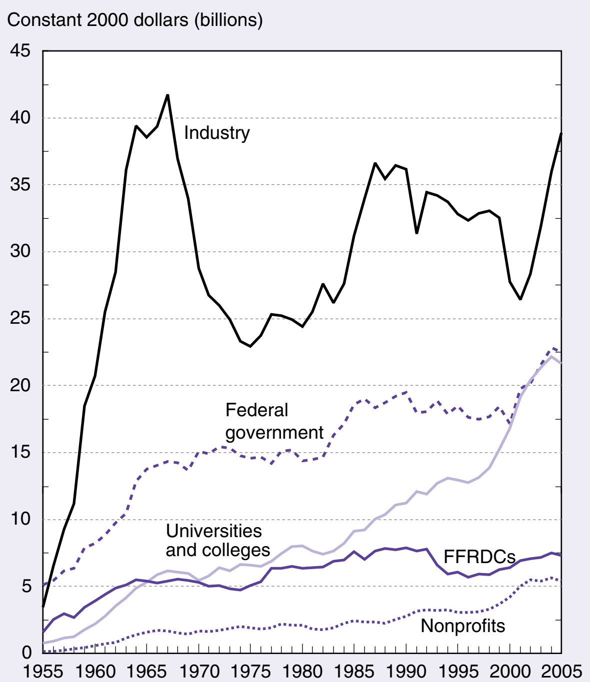
The federal government has historically been the primary source of R&D funding to universities and colleges, accounting for as much as two-thirds of all academic R&D funding in the early 1980s. (For more detailed information on academic R&D, see chapter 5). In 1955, obligations for academic R&D accounted for 7% of all federal R&D funding, or $0.75 billion in constant 2000 dollars. Fifty years later, R&D funding to academia represents 22% of all federal

R&D obligations, or $21.65 billion in constant 2000 dollars. As figure 4-9 illustrates, funding to academia grew rapidly after 1998, the result of a successful bipartisan effort to double the budget of NIH from its 1998 level over 5 years.

Federal Funding to Industry

Since 1956, the federal government has obligated the largest share of its R&D funding to industry. Federal funding for this sector, largely for development projects, has experienced more variability over the past 50 years than for any other sector (figure 4-9). R&D obligations to industry grew rapidly in the 1960s and peaked at $42 billion in constant 2000 dollars as the government invested heavily in its space program. Following the successful Apollo 11 mission to the moon, R&D obligations to industry declined and did not experience another surge until over a decade later, when Cold War investments in military technology resulted in another period of growth. Similarly, military investments following the events of September 11, 2001, resulted in an influx of federal R&D funding to industry. After adjusting for inflation, federal R&D obligations to industry increased by more than 47% from 2001 to 2005. Beginning in 1989, the amount of federally funded R&D reported by industry began to diverge from the amount reported by the federal government. For details on this discrepancy, see sidebar "Tracking R&D: Gap Between Performer- and Source-Reported Expenditures."

Figure 4-9
Federal obligations for R&D, by performing sector: FY 1955–2005



FFRDC = federally funded research and development center

NOTE: Preliminary 2005 data.

SOURCE: National Science Foundation, Division of Science Resources Statistics, *Federal Funds for Research and Development: Fiscal Years 2003, 2004, and 2005* (forthcoming).

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Federal Intramural R&D

In FY 2005, obligations for federal intramural R&D totaled $24.8 billion. These funds supported R&D performed at federal laboratories as well as costs associated with the planning and administration of both intramural and extramural R&D projects. Among individual agencies, DOD continued to fund the most intramural R&D and is expected to account for almost half of all federal obligations for intramural R&D in FY 2005 (table 4-8). DOD's intramural R&D obligations are more than twice that of the second largest R&D-performing agency, HHS, which performs most of its intramural R&D at NIH in Maryland. Only two other agencies report intramural R&D obligations in excess of $1 billion in FY 2005, NASA and USDA.

Federally Funded Research and Development Centers

FFRDCs are unique organizations that help the U.S. government meet special long-term research or development goals that cannot be met as effectively by in-house or contractor resources. (See sidebar, "Rationales for Federal Laboratories and FFRDCs.") According to the *Federal Register,* an FFRDC is required "to operate in the public interest with objectivity and independence, to be free from organizational conflicts of interest, and to have full disclosure of its affairs to the sponsoring agency" (National Archives and Records Administration [NARA] 1990). First established during World War II to assist DOD and DOE with R&D on nuclear weapons, FFRDCs today perform R&D with both defense and civilian applications.

Of the 36 FFRDCs active in 2003, DOE sponsors 16, or more than any other agency.[27] These 16 FFRDCs performed a total of $9.2 billion of R&D in 2003, or more than three-quarters of that performed by all FFRDCs combined (appendix table 4-25). Four FFRDCs reported R&D expenditures of more than $1 billion in 2003—Los Alamos National Laboratory, Sandia National Laboratories, Jet Propulsion Laboratory, and Lawrence Livermore National Laboratory—accounting for over half of all FFRDC R&D expenditures.

Federal Research Funding by Field

Federal agencies fund research in a wide range of S&E fields, from aeronautical engineering to sociology. The relative amount of research funding differs by field, as do trends in funding over time. According to preliminary estimates, federal obligations for research (excluding development) totaled $54.7 billion in FY 2005. Life sciences received the largest portion of this funding (54%, or $29.7 billion), followed by engineering (17%), physical sciences (10%), environmental sciences (7%), and mathematics and computer sciences (5%) (figure 4-11). Social sciences, psychology, and all other sciences accounted for the remainder.

HHS, primarily through NIH, provided the largest share (53%) of all federal research obligations in FY 2005, with

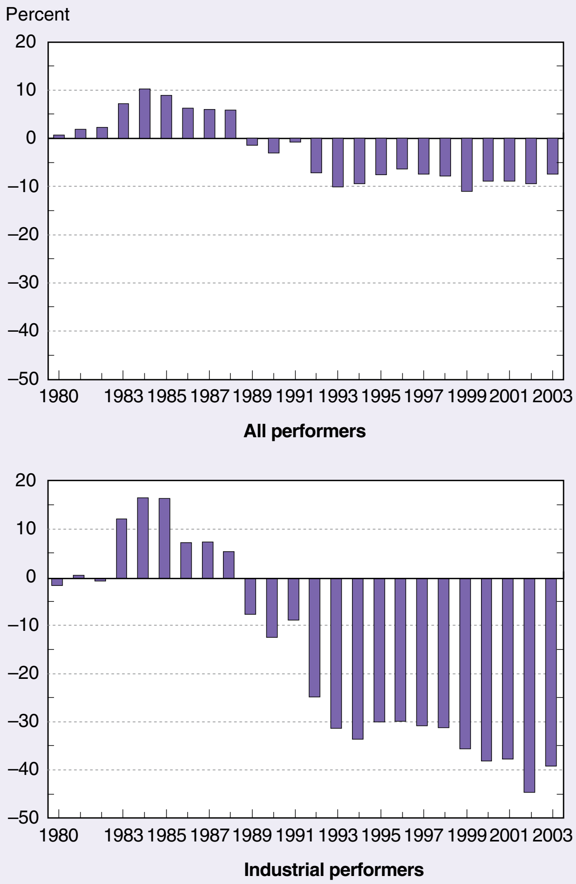
Tracking R&D: Gap Between Performer- and Source-Reported Expenditures

In many Organisation for Economic Co-operation and Development (OECD) countries, including the United States, total government R&D support figures reported by government agencies differ substantially from those reported by performers of R&D work. Consistent with international guidance and standards, most countries' national R&D expenditure totals and time series are based primarily on data reported by performers (OECD 2002b). This convention is preferred because performers are in the best position to indicate how much they spent conducting R&D in a given year and to identify the source of their funds. Although funding and performing series may be expected to differ for many reasons, such as different bases used for reporting government obligations (fiscal year) and performance expenditures (calendar year), the gap between the two R&D series has widened during the past several years.

For the United States, the reporting gap has become particularly acute over the past several years. In the mid-1980s, performer-reported federal R&D exceeded federal reports of funding by $3–$4 billion annually (5%–10% of the government total). This pattern reversed itself toward the end of the decade; in 1989 the government-reported R&D total exceeded performer reports by $1 billion. The gap subsequently grew to about $8 billion by 2002. In other words, almost 10% of the government total in 2002 was unaccounted for in performer surveys (figure 4-10). The difference in federal R&D totals was primarily in DOD development funding of industry. For 2002 federal agencies reported $29.5 billion in total R&D obligations to industrial performers, compared with $16.4 billion in federal funding reported by industrial performers. Overall, industrywide estimates equal a 44% paper "loss" of federally reported 2001 R&D support (figure 4-6). This discrepancy shrank in 2003 to 39%.

Several investigations into the possible causes for the data gap produced insights into the issue, but a conclusive explanation has been elusive. According to a recent investigation (U.S. General Accounting Office 2001b, p. 2), "Because the gap is the result of comparing two dissimilar types of financial data (federal obligations and performer expenditures), it does not necessarily reflect poor quality data, nor does it reflect whether performers are receiving or spending all the federal R&D funds obligated to them. Thus, even if the data collection and reporting issues were addressed, a gap would still exist." Echoing this assessment, the National Research Council (2005) notes that comparing federal outlays for R&D (as opposed to obligations) to performer expenditures results in a smaller discrepancy.

Figure 4-10
Difference in U.S. performer-reported and agency-reported federal R&D: 1980–2003



NOTE: Difference is defined as percentage of federally reported R&D, with a positive difference indicating that performer-reported R&D exceeds agency-reported R&D.

SOURCES: National Science Foundation, Division of Science Resources Statistics, *National Patterns of R&D Resources* (annual series); and, *Federal Funds for Research and Development: Fiscal Years 2003, 2004, and 2005* (forthcoming). See appendix table 4-29.

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most of its obligations funding medical and other related life sciences. The next four largest federal agencies in terms of research funding in FY 2005 were DOE (11%), DOD (10%), NASA (10%), and NSF (7%). DOE provides substantial funding for research in the physical sciences ($2.3 billion) and engineering ($2.0 billion). DOD's research funding is focused on engineering ($3.0 billion) and on mathematics and computer sciences ($0.8 billion). NASA's research funding also emphasizes engineering ($2.4 billion), followed by environmental sciences ($1.2 billion) and physical sciences ($1.1 billion). NSF, whose mission is to "promote the progress of science," has a more balanced research portfolio, contributing between $0.6 and $0.8 billion to researchers in each of the following groups of fields:

Table 4-8
Estimated federal total, intramural, and FFRDC R&D obligations, by agency: FY 2005
(Millions of dollars)

Agency	Total obligations	Intramural	FFRDC	Intramural plus FFRDC (%)
All federal government	106,487.8	24,813.0	8,058.6	30.9
Department of Defense	51,402.1	12,199.7	1,009.2	25.7
Department of Health and Human Services	28,865.6	5,810.1	602.9	22.2
National Aeronautics and Space Administration	8,114.0	2,028.5	1,411.8	42.4
Department of Energy	7,957.8	844.0	4,761.3	70.4
National Science Foundation	3,844.2	35.3	216.3	6.5
Department of Agriculture	1,969.3	1,333.7	0.0	67.7
Department of Commerce	979.3	800.5	0.6	81.8
Department of Transportation	736.8	228.2	10.7	32.4
Environmental Protection Agency	572.2	271.2	0.0	47.4
Department of the Interior	548.7	489.1	0.0	89.1
Department of Veterans Affairs	359.3	359.3	0.0	100.0
Department of Education	288.1	15.7	0.0	5.4
Agency for International Development	267.1	31.8	0.0	11.9
Smithsonian Institution	114.0	114.0	0.0	100.0
Department of Labor	107.6	92.0	0.0	85.5
Department of Justice	94.5	42.2	0.0	44.7
Nuclear Regulatory Commission	75.4	15.2	45.8	80.9
Social Security Administration	70.0	3.9	0.0	5.6
Department of the Treasury	68.7	62.5	0.0	91.0
Department of Housing and Urban Development	42.6	27.7	0.0	65.0
Federal Communications Commission	3.6	3.6	0.0	100.0
Library of Congress	2.6	2.6	0.0	100.0
Department of State	2.2	0.7	0.0	31.8
Federal Trade Commission	1.6	1.6	0.0	100.0
Appalachian Regional Commission	0.7	0.1	0.0	14.3
National Archives and Records Administration	0.1	0.1	0.0	100.0

FFRDC = federally funded research and development center

NOTE: Intramural activities include actual intramural R&D performance and costs associated with planning and administration of both intramural and extramural programs by federal personnel.

SOURCE: National Science Foundation, Division of Science Resources Statistics, *Federal Funds for Research and Development: Fiscal Years 2003, 2004, and 2005* (forthcoming).

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mathematics and computer sciences, physical sciences, environmental sciences, engineering, and life sciences.

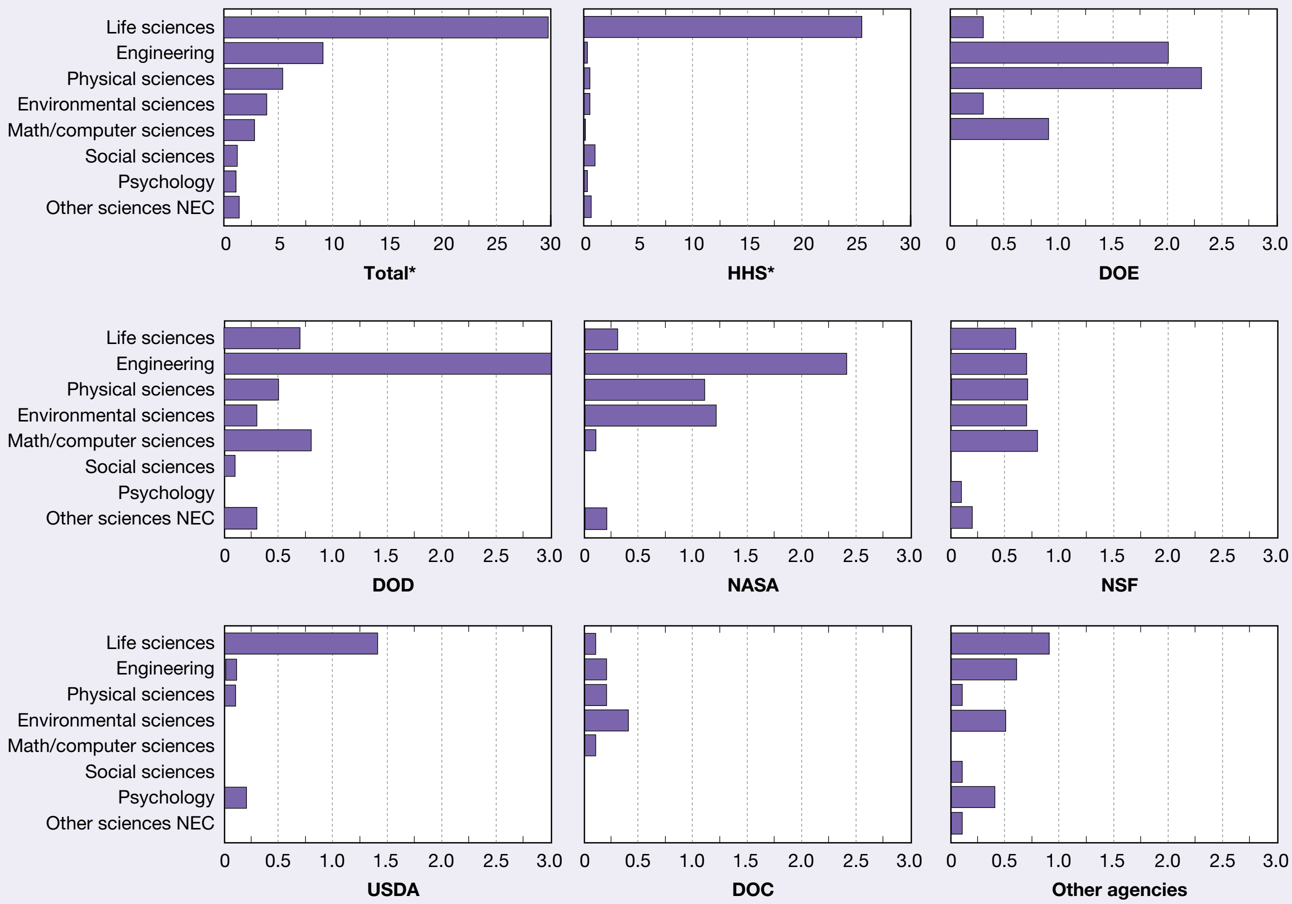
Federal obligations for research have grown at different rates for different S&E fields, reflecting changes in perceived public needs in those fields, changes in the national resources (e.g., scientists, equipment, and facilities) that have been built up in those fields over time, as well as differences in scientific opportunities across fields. Over the period 1984–2005, total federal research obligations grew, on average, 3.9% per year in real terms, from $22.2 billion in 2000 dollars to $49.5 billion in 2000 dollars. The groups of fields that experienced higher-than-average growth over this period were mathematics and computer sciences (6.7% per year in real terms), life sciences (5.7%), and psychology (6.7%) (appendix table 4-32). Funding for the remaining groups of fields also grew at a faster rate than inflation over this period: environmental sciences (3.0%), engineering (2.1%), social sciences (2.0%), and physical sciences (0.5%).

Caution should be employed when examining trends in federal support for more detailed S&E fields than those presented above because federal agencies classify a significant amount of R&D only by major S&E field, such as life sciences, physical sciences, or social sciences. In FY 2003, for example, 15% of the federal research obligations classified by major S&E field were not subdivided into detailed fields. This was less pronounced in physical sciences and in mathematics and computer sciences, in which all but 9% of the research dollars were subdivided. It was most pronounced in engineering and social sciences, in which, respectively, 35% and 62% of federal research obligations were not subdivided into detailed fields (appendix table 4-32).

Federal R&D Budget by National Objective

Before any agency can obligate funds for R&D, it must first have budget authority from Congress for such activity. In the president's FY 2006 budget submission to Congress, the proposed total federal budget authority for R&D is $127.5 billion. Adjusting for inflation, this amount is a 2% decline from the prior year's budget. This decline follows a 5-year period of increasing inflation-adjusted federal R&D budgets. Although

Figure 4-11
Estimated federal obligations for research, by agency and major S&E field: FY 2005
Current dollars (billions)



DOC = Department of Commerce; DOD = Department of Defense; DOE = Department of Energy; HHS = Department of Health and Human Services; NASA = National Aeronautics and Space Administration; NEC = not elsewhere classified; NSF = National Science Foundation; USDA = Department of Agriculture

*Scale differs for total and HHS from all other agencies.

SOURCE: National Science Foundation, Division of Science Resources Statistics, *Federal Funds for Research and Development: Fiscal Years 2003, 2004, and 2005* (forthcoming). See appendix table 4-31.

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R&D tends to be a popular budgetary item, the growing federal budget deficit may hamper future growth in federal R&D.

To assist Congress and the president in evaluating and adjusting the federal budget, OMB requests agencies to allocate their budget requests into specific categories called budget functions. These budget functions represent a wide range of national objectives the government aims to advance, from national defense to health to transportation. Changing trends in federal R&D budget authority by budget function tend to reflect shifts in presidential and congressional priorities (see sidebar "Federal R&D Initiatives").

Defense-Related R&D

The largest R&D budget function in the FY 2006 budget is defense, with a proposed budget authority of $74.8 billion, or 59% of the entire federal R&D budget. In 1980 the federal budget authority for defense-related R&D was roughly equal to that for nondefense R&D, but by 1985 defense R&D had grown to more than double nondefense R&D (figure 4-12). The gap between the defense and nondefense R&D budgets shrank almost every year after 1986 until 2001, when the defense budget function represented 53% of the federal R&D budget. The terrorist attacks of September 11, 2001, reversed this trend, and the annual federal defense R&D budget grew by $29 billion over the next 5 years.

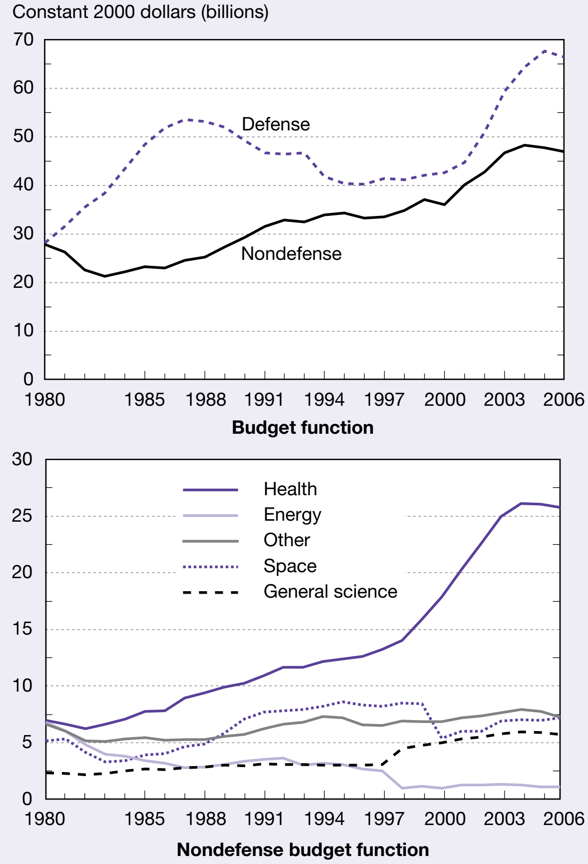
As described earlier, the majority of defense-related R&D goes toward the development of new and improved military technology, from weapons systems to communication technology. In FY 2006, DOD requested research, development, testing, and evaluation budgets in excess of $1 billion for four systems (US DOD 2005):

Federal R&D Initiatives

The Bush administration has identified a number of R&D priority areas that often involve the expertise of multiple federal agencies, from combating terrorism to developing hydrogen fuel cell technology. To improve the efficiency and effectiveness of federal R&D investments in these areas, the administration has encouraged strategic coordination among stakeholder agencies. The multiagency R&D priorities detailed in the administration's FY 2006 budget include:

- **Climate Change.** The Climate Change Science Program is focused on improving decisionmaking on climate change science issues. This program involves 13 departments and agencies and has an FY 2006 R&D budget of $1.9 billion, with the National Aeronautics and Space Administration (NASA) providing over 60% of the funding.
- **Combating Terrorism.** Following September 11, 2001, efforts were made to harness federal R&D programs that could help to deter, prevent, or mitigate terrorist acts. In the FY 2006 budget, over $4 billion is slated for homeland security-related R&D. Although the Department of Homeland Security has an important coordinating role in these R&D efforts, it is not the largest agency in terms of homeland-security R&D spending. The National Institutes of Health (NIH), with almost $1.8 billion targeted toward biodefense R&D, has the largest homeland security R&D budget.
- **Hydrogen Fuel.** The Hydrogen Fuel Initiative (HFI) seeks to support R&D aimed at developing and improving technologies for producing, distributing, and using hydrogen to power automobiles. The Department of Energy is the lead agency in this effort, with $258 million budgeted for HFI R&D in FY 2006.
- **Nanotechnology.** The National Nanotechnology Initiative (NNI) supports basic and applied research on the unique phenomena and processes that occur at the nanometer scale. NNI involves 11 R&D-funding agencies and an additional 11 coordinating agencies (such as the U.S. Patent and Trademark Office). The FY 2006 budget provides $1.1 billion in R&D support to NNI, with the largest investment ($344 million) to be made by the National Science Foundation (NSF).
- **Networking and Information Technology.** The multiagency Networking and Information Technology Research and Development (NITRD) program aims to leverage agency research efforts in advanced networking and information technologies. The FY 2006 budget provides $2.1 billion for NITRD R&D. Seven agencies participate in the program, with NSF providing the largest share of NITRD funding ($803 million).

Figure 4-12
Federal R&D budget authority, by budget function: FY 1980–2006



NOTES: Other includes all nondefense functions not separately graphed, such as agriculture and transportation. 1998 increase in general science and decrease in energy and 2000 decrease in space were results of reclassification.

SOURCE: National Science Foundation, Division of Science Resources Statistics, *Federal R&D Funding by Budget Function: Fiscal Years 2004–06* (forthcoming). See appendix table 4-26.

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- **Missile Defense ($8.1 billion):** "A multilayer, multifaceted program designed to protect the United States, our Allies and deployed forces from missile attack."
- **Joint Strike Fighter ($4.9 billion)**: "The Joint Strike Fighter (JSF) is the next-generation strike fighter for the Air Force, Marine Corps, Navy, and U.S. allies."
- **Future Combat System ($3.4 billion):** "The FCS [Future Combat System] R&D program will develop network centric concepts for a multi-mission combat system that will be overwhelmingly lethal, strategically deployable, self-sustaining and highly survivable in combat through the use of an ensemble of manned and unmanned ground and air platforms."
- **DD(X) Destroyer ($1.1 billion):** "DD(X) will be an optimally crewed, multi-mission surface combatant designed to fulfill volume firepower and precision strike requirements."

Civilian-Related R&D

R&D accounts for 13.3% of the FY 2006 federal nondefense discretionary budget authority of $398.5 billion.[28] Although this is less than that reserved for defense activities (16.9% of the $441.8 billion discretionary budget authority in FY 2006), over 90% of federal basic research funding is for nondefense budget functions, accounting for a large part of the budgets of agencies with nondefense missions such as general science (NSF), health (NIH), and space research and technology (NASA) (table 4-9; appendix table 4-27).

The most dramatic change in national R&D priorities over the past 25 years has been the growing importance of health-related R&D. As illustrated in figure 4-12, health-related R&D rose from representing 25% of the federal nondefense R&D budget allocation in FY 1980 to 55% in FY 2006. Most of this growth occurred after 1998, when NIH's budget was set on a pace to double by 2003 (Meeks 2002).

The budget allocation for space-related R&D peaked in the 1960s, during the height of the nation's efforts to surpass the Soviet Union in space exploration. Since the loss of the Space Shuttle Columbia and its crew of seven on 1 February 2003, manned space missions have been curtailed. Nonetheless, the proportion of the federal R&D budget for space research is slightly higher in 2006 (15.3%) than in 2003 (14.9%). In the president's FY 2006 budget, 54% of NASA's $16.5 billion discretionary budget was allocated for R&D.

Compared with that of health-related R&D, the budget allocation for general science R&D has grown relatively little in the past 25 years. In fact, the growth in general science R&D is more the result of a reclassification of several DOE programs from energy to general science in FY 1998 than the result of increased budget allocations (figure 4-12). The formation of the Department of Homeland Security (DHS) and the coincident reclassification of much of its formerly civilian R&D activities as defense R&D is a more recent example of how R&D budget function classifications can change when the mission or focus of funding agencies changes.

Federal S&T Budget

Alternative concepts have been used to isolate and describe fractions of federal support that could be associated with scientific achievement and technological progress. In a 1995 report, a National Academy of Sciences (NAS) committee proposed an alternative method of measuring the federal government's S&T investment (NAS 1995). According to the committee members, this approach, called the federal science and technology (FS&T) budget, might provide a better way to track and evaluate trends in public investment in R&D. The FS&T concept differed from the traditional federal R&D data definitions used earlier in this section in that it did not include major systems development supported by DOD and DOE, and it contained not only research but also some development and some R&D plant.

Beginning with the FY 2000 budget, OMB has presented its concept for an FS&T budget (figure 4-13). Whereas the NAS FS&T compilation included only R&D, OMB's FS&T budget was compiled from easily tracked programs and included some non-R&D programs, such as NSF education programs and staff salaries at NIH and NSF.

In the 2006 Budget of the United States, OMB's FS&T budget is less than half the total federal R&D budget because it excludes funding for defense development, testing, and evaluation. It includes nearly all budgeted federal support

Table 4-9
Budget authority for R&D, by federal agency and character of work (proposed levels): FY 2006
(Millions of current dollars)

Agency	Total discretionary budget authority	Total R&D	Basic research	Applied research and development	R&D share of discretionary budget (%)
All federal government	840,306	127,506	26,608	100,898	15.2
Department of Defense	419,341	70,789	1,319	69,470	16.9
Department of Health and Human Services	68,858	28,684	15,246	13,438	41.7
National Aeronautics and Space Administration	16,456	8,943	2,199	6,744	54.3
Department of Energy	23,441	7,430	2,762	4,668	31.7
National Science Foundation	5,606	3,756	3,480	276	67.0
Department of Agriculture	19,366	1,876	788	1,088	9.7
Department of Homeland Security	29,342	1,257	112	1,145	4.3
Department of Commerce	9,403	924	71	853	9.8
Department of Transportation	11,815	789	41	748	6.7
Department of Veterans Affairs	31,274	786	315	471	2.5
Department of Interior	10,643	579	30	549	5.4
Environmental Protection Agency	7,571	569	70	499	7.5
Other	187,190	1,124	175	949	0.6

SOURCE: U.S. Office of Management and Budget, *Budget of the United States Government, Fiscal Year 2006* (2005).

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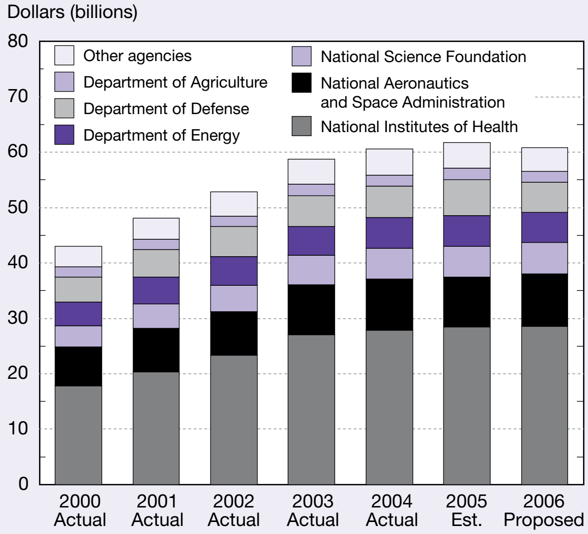
Figure 4-13
Federal science and technology budget, by agency: FY 2000–06



SOURCES: U.S. Office of Management and Budget, Analytical Perspectives, *Budget of the United States Government, Fiscal Year 2002, Fiscal Year 2003, Fiscal Year 2004, Fiscal Year 2005, and Fiscal Year 2006.*

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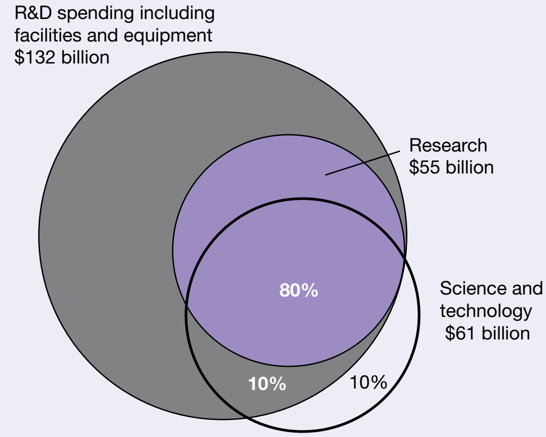
Figure 4-14
Federal funding concepts in budget proposal: FY 2006



NOTE: Percents represent shares of the federal science and technology budget rounded to the nearest 10%.

SOURCE: U.S. Office of Management and Budget, *Analytical Perspectives, Budget of the United States Government: Fiscal Year 2006* (2005).

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for basic research in FY 2004, more than 80% of federally supported applied research, and about half of federally supported nondefense development.

As shown in figure 4-14, federal R&D in the 2006 budget proposal, which includes expenditures on facilities and equipment, would reach a level of $132 billion. Of this amount, $55 billion would be devoted to basic and applied research alone. The FS&T budget would reach $61 billion and would include most of the research budget. However, differences in the definition of research and FS&T imply that not all research would be included in FS&T and vice versa. Moreover, a small proportion (10%) of FS&T funds would fall outside the traditional definition of federal R&D spending.

Federal R&E Tax Credit

Background

One of the better-known indirect federal incentives for fostering industrial R&D is the research and experimentation (R&E) tax credit.[29] The traditional justification for incentives for research is that results from these activities, especially more basic or long-term research, are often hard to capture privately because others might benefit directly or indirectly from them. Therefore, businesses might engage in levels of research below those that would be beneficial to the nation as a whole. Across advanced economies, R&D tax credits vary in terms of how they are structured or targeted, their effect on public budgets, and their effectiveness in stimulating innovation (Bloom, Griffith, and Van Reenan 2002; OECD 2003).[30]

The federal R&E tax credit was established by the Economic Recovery Tax Act of 1981, one of several policy tools put in place in the 1980s to address perceived problems in the competitive position of U.S. companies (Guenther 2005). The credit is subject to periodic extensions given its temporary status. It was renewed most recently by the Working Families Tax Relief Act of 2004 through 31 December 2005.[31]

The credit is designed to stimulate company R&D over time by reducing after-tax costs. Specifically, companies that qualify for the credit can deduct or subtract from corporate income taxes an amount equal to 20% of qualified research expenses above a base amount.[32] For established companies, the base amount depends on historical expenses over a statutory base period relative to gross receipts, whereas startup companies follow other provisions. An alternative R&E credit has been available since 1996. This credit has a lower base amount and a maximum statutory rate of 3.75%. The alternative credit benefits established companies that have smaller annual increases relative to their base period (Hall 2001). Companies may select only one of these two credits on a permanent basis, unless the Internal Revenue Service (IRS) authorizes a change. Both types of R&E credit include provisions for basic research payments to qualified universities or scientific research organizations.

Tax Credit Claims

According to data from the IRS' Statistics of Income (SOI), R&E tax credit claims reached an estimated $6.4 billion in 2001 ($6.2 billion in constant or inflation-adjusted dollars), compared with the all-time high of $7.1 billion in 2000 (table 4-10).[33] From 1990 to 2001, the annual dollar amount of R&E credit claims grew twice as fast as industry-funded

Table 4-10
Federal research and experimentation tax credit claims and corporate tax returns claiming credit: 1990–2001

Year	Tax credit claims ($ millions) Current	Constant	Tax returns
1990	1,547	1,896	8,699
1991	1,585	1,877	9,001
1992	1,515	1,754	7,750
1993	1,857	2,101	9,933
1994	2,423	2,684	9,150
1995	1,422	1,544	7,877
1996	2,134	2,274	9,709
1997	4,398	4,609	10,668
1998	5,208	5,399	9,849
1999	5,281	5,396	10,019
2000	7,079	7,079	10,495
2001	6,356	6,207	10,388

NOTE: Data exclude IRS forms 1120S (S corporations), 1120-REIT (Real Estate Investment Trusts), and 1120-RIC (Regulated Investment Companies). Constant dollars based on calendar year 2000 gross domestic product price deflator.

SOURCE: Internal Revenue Service, Statistics of Income program, special tabulations.

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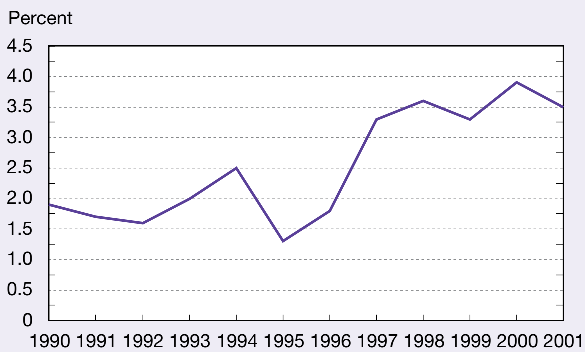
Figure 4-15
Research and experimentation tax credit claims as percentage of industry-funded R&D expenditures: 1990–2001



SOURCES: U.S. Internal Revenue Service, Statistics of Income program, special tabulations; and National Science Foundation, Division of Science Resources Statistics, *National Patterns of Research and Development Resources: 2003*, NSF 05-308 (2005).

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R&D, after adjusting for inflation (NSF/SRS 2005), but growth in credit claims varied throughout the decade. From 1990 to 1996, companies claimed between $1.5 billion and $2.5 billion in R&E credits annually; since then, annual R&E credits have exceeded $4 billion (table 4-10). However, R&E tax credit claims still accounted for less than 4% of industry-funded R&D expenditures as of 2001 (figure 4-15).

Data are available on the industry classification of companies that claim the R&E tax credit for 1998–2001 using the new North American Industry Classification System (NAICS) (appendix table 4-33). Since 1998, corporate tax returns classified in five industries accounted for 80% or more of R&E credit claims. In 2001, the top five industries accounted for 80% of credit claims ($5.1 billion of the $6.4 billion):

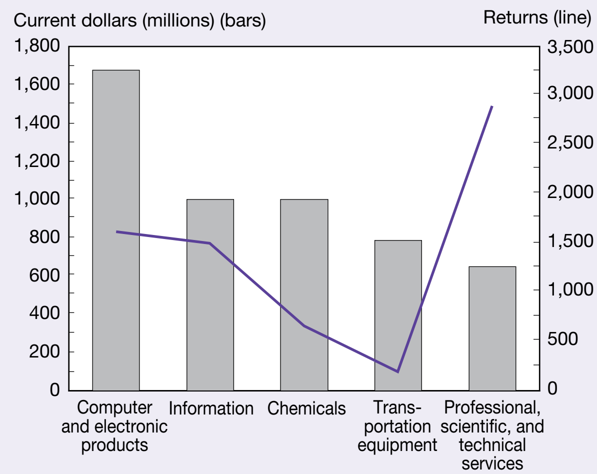
- Computer and electronic products (26%)
- Information, including software (16%)
- Chemicals, including pharmaceuticals and medicines (16%)
- Transportation equipment, including motor vehicles and aerospace (12%)
- Professional, scientific, and technical services, including computer services and R&D services (10%)

The number of corporate tax returns claiming the R&E tax credit grew at a slower rate than their dollar R&E credit claims, fluctuating between 8,000 and 10,000 tax returns over most of the 1990s (table 4-10). In 2001, companies in the professional, scientific, and technical services industry filed more corporate tax returns claiming the R&E tax credit than did any other industry. That industry represented about 28% of all returns claiming the credit, followed by computer and electronic products and information, each with about 15% (figure 4-16).

Technology Linkages: Contract R&D, Public-Private Partnerships, and Industrial Alliances

Increasingly, industrial innovation involves a combination of R&D performed internally and a host of activities with external partners (Adams 2005, pp 131–3). Technology

Figure 4-16
Industries with largest research and experimentation tax credit claims and corporate tax returns claiming credit: 2001



SOURCE: U.S. Internal Revenue Service, Statistics of Income program, special tabulations. See appendix table 4-33.

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activities or transactions with external partners (such as contract R&D and technology alliances) may reduce costs, expedite projects, or complement internal capabilities, but they may also present strategic and management challenges compared to in-house R&D (Cassiman and Veugelers 2002). At the same time, firms are likely to benefit more from a combination of innovation strategies than from any single tool.

At the macro level, a systems approach to innovation recognizes the importance of cross-sector linkages between R&D performers and users involving different levels of knowledge (e.g., scientific findings, technological practices) and goals (e.g., commercialization, public health, or student training). Public policies in the United States and other advanced economies, concerned with enhancing the prospects of technology-based economic growth, have evolved to address the many dimensions of industrial innovation. In the United States, several policies have facilitated R&D collaboration among industry, universities, and federal laboratories (see sidebar "Major Federal Legislation Related to Cooperative R&D and Technology Transfer").

This section discusses trends affecting selected indicators of industrial technology linkages—contracted-out R&D, industrial technology alliances, and federal technology programs—including the following key findings:

- The average annual growth rate of contracted-out R&D from 1993 to 2003 was double the growth rate of in-house company-funded R&D, after adjusting for inflation, indicating an increasing role for external sources of technology. For manufacturing companies, contracted-out R&D grew almost three times as fast as R&D performed internally.
- Industrial technology alliances worldwide reached an all-time annual peak in 2003 with 695 alliances. These alliances involve mostly companies from the United States, Europe, and Japan that focus to a large extent on biotechnology and information technology products, services, or techniques. Alliances involving only U.S.-owned companies have represented the largest share of alliances in most years since 1980, followed by alliances between U.S. and European companies.
- Public-private partnerships include a combination of joint funding, collaborative activities, or procurement policies. For example, federal agencies participated in a total of 2,936 cooperative research and development agreements (CRADAs) with industrial firms and other

Major Federal Legislation Related to Cooperative R&D and Technology Transfer

- **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.
- **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.
- **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 that has commercialization potential within small high-technology companies.
- **National Cooperative Research Act (1984)**—encouraged U.S. firms to collaborate on generic, precompetitive research by establishing a rule of reason for evaluating the antitrust implications of research joint ventures. The act was amended in 1993 by the National Cooperative Research and Production Act (NCRPA), which let companies collaborate on production activities as well as research activities.
- **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 entities, including other federal agencies, state or local governments, universities and other nonprofit organizations, and industrial companies.
- **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 the Advanced Technology Program and the Manufacturing Technology Centers within the National Institute for Standards and Technology to help U.S. companies become more competitive.
- **National Competitiveness Technology Transfer Act** (1989)—amended the Stevenson-Wydler Act to allow government-owned, contractor-operated laboratories to enter into CRADAs.
- **National Cooperative Research and Production Act (1993)**—relaxed restrictions on cooperative production activities, enabling research joint venture participants to work together in the application of technologies they jointly acquire.
- **Technology Transfer Commercialization Act (2000)**—amended the Stevenson-Wydler Act and the Bayh-Dole Act to improve the ability of government agencies to monitor and license federally owned inventions.

organizations in FY 2003, up 4.3% from a year earlier, but still below the 3,500 peak in FY 1996. DOD and DOE executed three-fourths of CRADAs in FY 2003; HHS participated in another 9% of the total.

- ♦ Federal programs focused on small firms or on early-stage technologies have been in place in the United States since the 1980s. The Small Business Innovation Research (SBIR) program and its sister program, the Small Business Technology Transfer Program (STTR), set aside a portion of existing federal R&D funds for small businesses. From FY 1983 to FY 2003, SBIR has awarded over $15 billion to 76,346 projects in areas such as computers and electronics, information services, materials, energy, and life sciences. DOD and HHS combined have provided between 60% and 80% of total annual SBIR funds since the program's inception. The Advanced Technology Program (ATP), housed at DOC's National Institute of Standards and Technology, was created to promote the development and commercialization of generic technologies through a competitive process on a cost-share basis with industry. Through FY 2004, ATP has awarded 768 projects with a combined funding of $4.37 billion involving over 1,500 participants; these include startups, established companies, and universities.

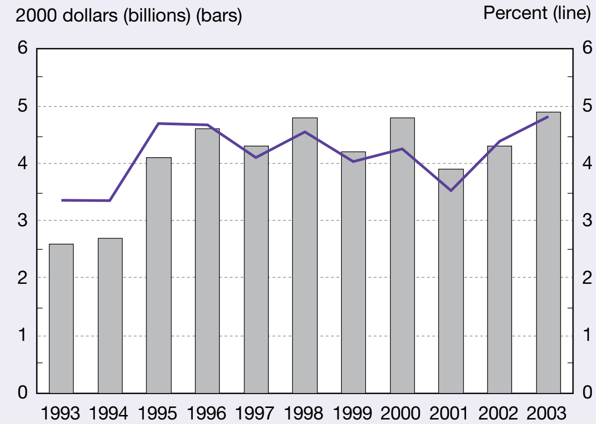
Contract R&D Expenses

In 2003, R&D-performing companies in the United States reported $10.2 billion (including $5.2 billion reported by manufacturers) in R&D contracted out to other domestic companies, compared with $183.3 billion in company-funded R&D performed internally, according to NSF's Survey of Industrial Research and Development (appendix table 4-34).[34]

A comparison between contracted-out and in-house R&D expenditures over time provides an indication of the importance of external R&D sources in a global competitive environment characterized by rapid technological developments, demands for innovative products, and cost and time constraints. The average annual growth rate of contracted-out R&D from 1993 to 2003 (9.4%, after adjusting for inflation) was about double the growth rate of in-house company-funded R&D (4.9%). For manufacturing companies, contracted-out R&D grew almost three times as fast as R&D performed internally, after adjusting for inflation. In 2003, the ratio of contracted-out R&D to in-house R&D was 5.7% for the aggregate of all industries, compared with 3.7% in 1993 (appendix table 4-34). The ratio for manufacturing in 2003 was 4.8%, lower than for the aggregate of all industries, but slightly above its previous peak in the mid-1990s (figure 4-17).

Chemical companies reported $2.8 billon in contracted-out R&D in 2003, of which $2.7 billion was reported by pharmaceuticals and medicines (appendix table 4-35).[35] The latter sector had the highest ratio of contracted-out R&D to R&D performed internally among major R&D-performing industries (17.1%, or $2.7 billion compared with $15.9

Figure 4-17
Manufacturing R&D expenditures contracted out in United States and ratio to company-funded R&D performed within companies: 1993–2003



SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Industrial Research and Development (annual series). See appendix table 4-34.

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billion in company-funded R&D performed internally). The second highest ratio among major R&D-performing industries was reported by scientific R&D services, with 14.5% ($1.5 billion in contracted-out R&D compared with $10.5 billion R&D performed internally). Transportation equipment and computer and electronic product companies reported 4.3% and 1.4% in contracted-out R&D expenses, respectively.

Industrial Technology Alliances

Industrial technology alliances are one of several tools aimed at the codevelopment of new products or capabilities.[36] Firm-specific drivers for R&D collaboration include cost and risk reductions afforded by pooling resources, as well as strategic or long-term considerations regarding the acquisition of innovation capabilities or entry into new product markets (Miotti and Sachwald 2003; Sakakibara 2001). Other factors include the increased complexity and industry-relevance of scientific research, especially in sectors such as biotechnology, and the policy environment, notably antitrust regulation and intellectual property protection.[37] In the United States, restrictions on multifirm cooperative research were loosened by the National Cooperative Research Act (NCRA) in 1984 (Public Law 98-462) after concerns about the technological leadership and international competitiveness of American firms in the early 1980s.[38] More recently, federal patent and trademark law was amended in order to facilitate patenting inventions resulting from collaborative efforts across different companies or organizations.[39] R&D collaborations share a number of challenges with other business collaborations, including management and coordination issues, and they also present unique issues due to the rising strategic value of innovation in an increasingly knowledge-based economy (Narula 2003).

Trends in the number of R&D technology alliances being formed provide an indication of firms partnering to develop and subsequently exploit new technologies. NSF funds two databases on technology alliances with different sources and scope: the Cooperative Research (CORE) database and the Cooperative Agreements and Technology Indicators database, Maastricht Economic Research Institute on Innovation and Technology (CATI-MERIT). CORE records U.S. alliances registered at the U.S. Department of Justice pursuant to the National Cooperative Research and Production Act (NCRPA).[40] CATI-MERIT covers domestic and international technology agreements and is based on public announcements, tabulated according to the country of ownership of the parent companies involved.[41]

Registered U.S. Cooperative Research Agreements

There were 22 industrial R&D alliances newly registered in 2003, according to the CORE database, for a total of 913 registered agreements since 1985. Fifteen percent (133 of 913) of these alliances involved a U.S. university as a research member, whereas 12% (111 of 913) included a federal laboratory. The number of newly registered alliances has declined annually in 5 of the last 7 years since the 1995 peak (figure 4-18). Trends in the CORE database are illustrative only, because the registry is not intended to be a comprehensive count of cooperative activity by U.S.-based firms.[42]

The CORE database now provides the industrial distribution of alliances based on the NAICS code for 446 of the 524 alliances from 1994 to 2003 (appendix table 4-36). Of these 446 alliances, two-thirds were classified in four manufacturing industries: electrical equipment, appliances, and components; transportation equipment; chemical (which includes pharmaceuticals); and computer and electronic products. Another 31 alliances (or 7%) were classified in professional, scientific, and technical services (which includes R&D services).

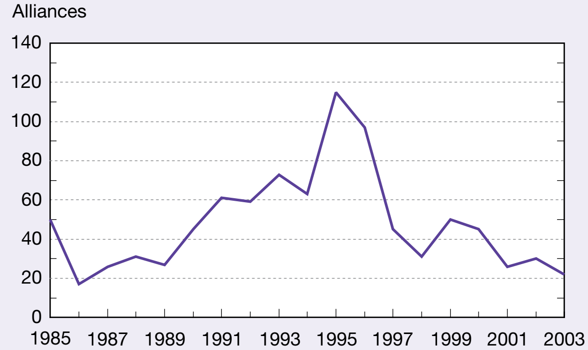
Domestic and International Technology Alliances

According to the CATI-MERIT database, new industrial technology alliances worldwide reached an all-time peak in 2003 with 695 alliances. These alliances involve mostly companies from the United States, Europe, and Japan focusing to a large extent on biotechnology and information technology products, services, or techniques (figure 4-19; appendix table 4-37).[43] Other technology areas include advanced materials, aerospace and defense, automotive, and (nonbiotechnology) chemicals.[44] In the 1990s information technology dominated R&D alliance activity (figure 4-20). However, the share of biotechnology alliances increased steadily over the decade, surpassing information technology alliances by 2000 and reaching 63% of alliances in 2002 and 53% in 2003.

Alliances involving only U.S.-owned companies have represented the largest share of alliances in most years since 1980, followed by alliances between U.S. and European companies (figure 4-21). However, the annual share of U.S.-Japan alliances declined from a peak of 21% of CATI-MERIT alliances in the early 1980s to 10% or less since the mid-1990s. The annual share of alliances formed exclusively among European companies has fluctuated between 10% and 20% since the late 1980s (figure 4-22). Other pairings account for single-digit shares in the database.

The apparent attractiveness of U.S. companies as global R&D partners has been attributed to the comparative advantage of the United States in certain high-technology sectors (Miotti and Sachwald 2003). At the same time, foreign direct investment by U.S. MNCs and overseas R&D by their

Figure 4-18
Industrial technology alliances registered under National Cooperative Research and Production Act: 1985–2003



NOTE: Data are annual counts of new alliances.

SOURCE: University of North Carolina–Greensboro, Cooperative Research (CORE) database, special tabulations.

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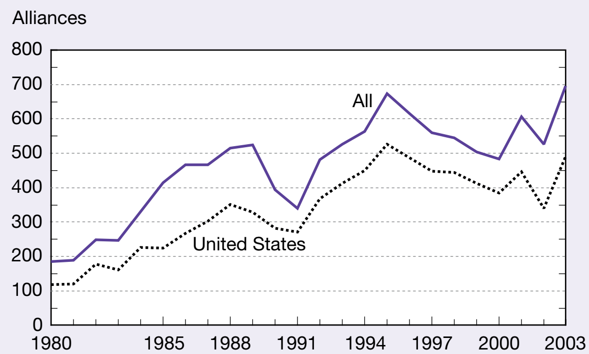
Figure 4-19
Worldwide industrial technology alliances and those with at least one U.S.-owned company: 1980–2003



NOTE: Data are annual counts of new alliances.

SOURCE: Maastricht Economic Research Institute on Innovation and Technology, Cooperative Agreements and Technology Indicators (CATI-MERIT) database, special tabulations. See appendix table 4-37.

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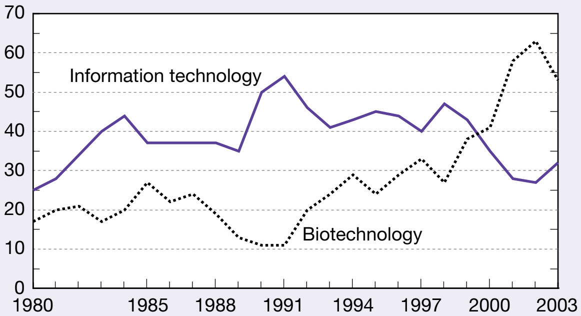
Figure 4-20
Information technology and biotechnology shares of industrial technology alliances: 1980–2003



SOURCE: Maastricht Economic Research Institute on Innovation and Technology, Cooperative Agreements and Technology Indicators (CATI-MERIT) database, special tabulations. See appendix table 4-37.

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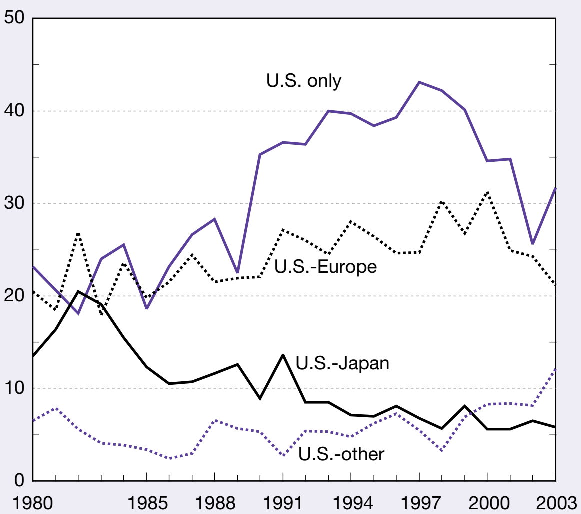
Figure 4-21
Share of industrial technology alliances involving at least one U.S. company, by country/region of partner: 1980–2003



SOURCE: Maastricht Economic Research Institute on Innovation and Technology, Cooperative Agreements and Technology Indicators (CATI-MERIT) database, special tabulations. See appendix table 4-37.

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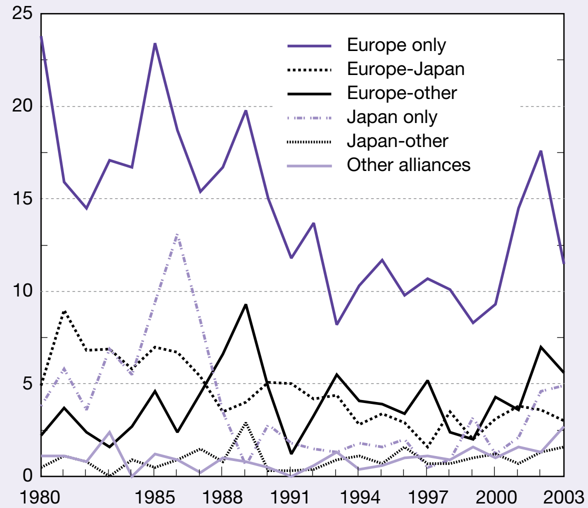
foreign affiliates (see "R&D Investments by Multinational Corporations" in this chapter) have increased the pool of potential U.S.-owned R&D partners available internationally.

Figure 4-22
Share of industrial technology alliances among non-U.S. companies, by country/region of partner: 1980–2003



SOURCE: Maastricht Economic Research Institute on Innovation and Technology, Cooperative Agreements and Technology Indicators (CATI-MERIT) database, special tabulations. See appendix table 4-37.

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Technology-Based Public-Private Partnerships

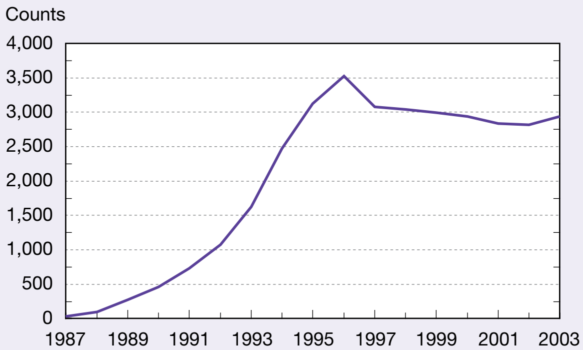
Public-private partnerships involve cooperative R&D among industry, universities, and government laboratories. They can facilitate technology transfer from the research laboratory to the market in support of both public agency mission as well as technology-based regional or national economic growth (NRC 2003). Partnerships may include a combination of joint funding, collaborative activities, or procurement policies ranging from formal R&D agreements between industrial companies and government laboratories, to research or science parks, to programs targeted for small firms and/or early-stage technologies. This section reviews CRADAs and other federal technology transfer indicators, the SBIR program, and the ATP.

Federal Laboratory Technology Transfer and CRADAs

Federal laboratories, whether run by federal agencies themselves or by contractors,[45] represent a key component of the U.S. innovation system both for federal missions such as defense, health, and energy, and as a source for industry-relevant knowledge (Crow and Bozeman 1998). Technology transfer refers to the exchange or sharing of knowledge, skills, processes, or technologies across different organizations. Federal technology transfer statutes apply to federally owned or originated technology (see sidebar "Major Legislation Related to Cooperative R&D and Technology Transfer").

CRADAs are one of several technology-based industry-government collaboration tools available in the United States.[46] Federal laboratories entering into CRADAs with industrial firms and other organizations may share personnel, services, or facilities (but not funds) as part of a joint R&D project with the potential to promote industrial innovation consistent with the agency's mission. Private partners may retain ownership rights or acquire exclusive licensing rights for the developed technologies.

Figure 4-23
Federal laboratory CRADAs: FY 1987–2003



CRADA = cooperative research and development agreement

NOTES: Data for active traditional CRADAS: those legally in force at any time during fiscal year and involving collaborative R&D by federal laboratory and nonfederal partners. FY 1999 data and beyond may not be comparable with prior years because of methodological changes in data collection and processing.

SOURCES: U.S. Department of Commerce, Office of the Secretary, *Summary Report on Federal Laboratory Technology Transfer: 2002 Report to the President and the Congress Under the Technology Transfer and Commercialization Act* (2002); and *Summary Report on Federal Laboratory Technology Transfer: FY 2003 Activity Metrics and Outcomes, 2004 Report to the President and the Congress Under the Technology Transfer and Commercialization Act* (2004). See appendix table 4-38.

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Simple CRADA counts offer a limited but illustrative window for viewing overall trends and agency participants.[47] Data on these and other federal technology transfer activities are available from the DOC, pursuant to federal technology transfer statutes (U.S. DOC 2004).[48] The 10 agencies reporting data were DOC, DOD, DOE, DOI, the Department of Transportation, the Environmental Protection Agency, HHS, NASA, USDA, and the Department of Veterans Affairs. Available metrics indicate substantial federal technology transfer activities, especially by agencies with the largest intramural and FFRDC R&D budgets.

Federal laboratories participated in a total of 2,936 CRADAs[49] in FY 2003, up 4.3% from a year earlier but still below the 3,500 peak in FY 1996 (figure 4-23). CRADA and other technology transfer activities are highly concentrated. DOD and DOE executed three-fourths of CRADAs in FY 2003; HHS participated in another 9% of the total.

DOE, DOD, HHS, and NASA topped metrics for inventions disclosures, patents, and invention licenses (table 4-11; appendix table 4-38).[50] An inventions disclosure documents an invention and may or may not result in a patent application. Patent and invention licenses (which include licenses of patented inventions) are indicators further along the chain of the technology transfer process in which laboratory results within an agency may find a useful application in agency missions or the marketplace.[51]

Differences in R&D funding structure (intramural versus extramural funding) and the R&D character of work across agencies may drive the agency distribution of these indicators. For example, the same four agencies had the largest FY 2003 intramural and FFRDC R&D budgets among all reporting agencies (table 4-12). Furthermore, the majority of their intramural and FFRDC R&D funds were devoted to applied research and development, similar to the distribution of industry's own R&D activities.[52]

Table 4-11
Federal laboratories technology transfer indicators, by selected agency: FY 2003

	Inventions disclosed		Patents issued		All active invention licenses	
Agency	Number	Percent distribution	Number	Percent distribution	Number	Percent distribution
All 10	4,348	100.0	1,607	100.0	3,656	100.0
Top 4	4,009	92.2	1,518	94.5	3,177	86.9
DOD	1,332	30.6	619	38.5	361	9.9
DOE	1,469	33.8	627	39.0	1,223	33.5
HHS	472	10.9	136	8.5	1,298	35.5
NASA	736	16.9	136	8.5	295	8.1

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

NOTES: Inventions disclosed and patents issued in FY 2003. Total active licenses are licenses active as of FY 2003, regardless of year issued.

SOURCE: U.S. Department of Commerce, Office of the Secretary, *Summary Report on Federal Laboratory Technology Transfer: FY 2003 Activity Metrics and Outcomes, 2004 Report to the President and the Congress Under the Technology Transfer and Commercialization Act* (2004). See appendix table 4-38.

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Table 4-12
Federal R&D obligations by selected agency, performer, and applied research and development component: FY 2003

Agency	Federal R&D obligations (current $ millions)				
	Total	Intramural and FFRDCs	Intramural and FFRDCs applied research and development	Intramural and FFRDCs share of total (%)	Applied research and development share of intramural and FFRDCs (%)
All federal agencies	93,662	30,477	23,092	32.5	75.8
DOD	42,031	11,771	11,345	28.0	96.4
DOE	7,412	5,195	3,431	70.1	66.1
HHS	26,399	5,874	2,956	22.3	50.3
NASA	7,499	3,232	2,293	43.1	70.9
Others	10,321	4,406	3,067	42.7	69.6

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

NOTE: Intramural activities include actual intramural R&D performance and costs associated with planning and administration of both intramural and extramural programs by federal personnel.

SOURCE: National Science Foundation, Division of Science Resources Statistics, *Federal Funds for Research and Development: Fiscal Years 2003, 2004, and 2005* (forthcoming).

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Science and Technology Programs

Programs focused on small firms or on early-stage technologies have been in place in the United States since the 1980s. The intangible and uncertain nature of R&D projects presents financing challenges, even within large companies. Small or new technology-based firms are known to have additional financing constraints given the early stage of their technologies, compared to activities closer to market applications by larger or established companies (Bougheas 2004**;** Branscomb and Auerswald 2002). At the same time, the economic role of startups, corporate or university spinoffs, and technology-based entrepreneurship has been increasingly recognized in the United States and in other R&D-intensive economies (Gilbert et al 2004).

Small Business Programs. Federal agencies participating in the SBIR program reserve a portion of a their extramural R&D budget for awards to small businesses (U.S. Code Title 15, Section 631). SBIR was created by the Small Business Innovation Development Act of 1982 (Public Law 97-219) and was last reauthorized in 2000 through September 2008.[53] Statutory goals include increasing the participation of small firms and companies owned by minorities or disadvantaged individuals in the procurement of federal R&D, and the promotion of technological innovation through commercialization of federally funded projects. The 1992 SBIR reauthorization bill[54] stipulated a stronger emphasis on the technology commercialization objectives of the program (Cooper 2003; NRC 2004). As of FY 2004, a total of 11 federal agencies participate in the program, including the new Department of Homeland Security (see sidebar "The New SBIR Program at the Department of Homeland Security").

SBIR's sister program, the STTR, was created in 1992 to stimulate cooperative R&D and technology transfer involving small businesses and nonprofit organizations, including universities and FFRDCs.[55] SBIR and STTR are administered by participating agencies and coordinated by the Small Business Administration.

According to the SBIR statute, federal agencies with extramural R&D obligations exceeding $100 million must set aside a fixed percentage of such obligations for SBIR projects. This set-aside has been 2.5% since FY 1997. To obtain this federal funding, a small company applies for a Phase I SBIR grant of up to $100,000 for up to 6 months to assess the scientific and technical feasibility of ideas with commercial potential. If the concept shows further potential, the company can receive a Phase II grant of up to $750,000 over a period of up to 2 years for further development. 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.

Through FY 2003, SBIR has awarded over $15 billion to 76,346 projects. Funded technology areas include computers and electronics, information services, materials, energy, and life sciences applications. In FY 2003 the program awarded $1.67 billion in R&D funding to 6,224 projects (figure 4-24). The upward trend in awards and funding reflects both the increased set-aside percentage over the history of the program as well as trends in federal funds for extramural R&D. DOD and HHS, combined, have provided between 60% and 80% of total annual SBIR funds since the program's inception (appendix table 4-39).

STTR involves cooperative R&D performed jointly by small businesses and nonprofit research organizations and is also structured in three phases. As of FY 2003, five federal agencies with extramural R&D budgets exceeding $1 billion participate in the program: DOD, NSF, DOE, NASA,

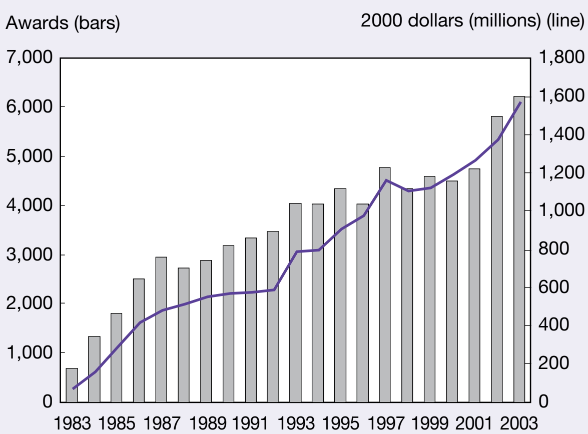
The New SBIR Program at the Department of Homeland Security

The Department of Homeland Security (DHS), established by the Homeland Security Act of 2002 and formed in January 2003, held its first SBIR competition in FY 2004 at its Homeland Security Advanced Research Projects Agency (HSARPA). Research topics of interest to DHS include chemical and biological sensors, ship compartment inspection devices, personal protective equipment and materials for emergency responders, and modeling and simulation technology.

According to DHS, "the FY 2005 SBIR funding level will be approximately $23 million…an increase from the FY 2004 funding level of just under $20 million.…The additional funding will also be useful as HSARPA begins a technology assistance program which can provide either technical assistance or commercialization support to the small businesses who gain DHS SBIR awards."* DHS also has implemented a Fast Track process for SBIR projects that successfully complete a Phase I project and receive a commitment for matching funds from outside investors for an eventual Phase II award.

*http://www.hsarpasbir.com/WhatsNew.asp. Accessed June 2005.

Figure 4-24
SBIR awards and funding: 1983–2003



SBIR = Small Business Innovation Research Program

SOURCE: U.S. Small Business Administration, *Small Business Innovation Research Program Annual Report* (various years). See appendix table 4-39.

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and HHS. Starting in FY 2004, the required set-aside rose from 0.15% to 0.3%, compared with a 2.5% set aside for SBIR. From FY 1994 to FY 2003, STTR awarded over $640 million to 3,422 projects. In FY 2003, the five participating agencies awarded $92 million, of which DOD and HHS represented a combined 80% (appendix table 4-40).

The Advanced Technology Program. The ATP, housed at DOC's National Institute of Standards and Technology (NIST), was established by the Omnibus Trade and Competitiveness Act of 1988 to promote the development and commercialization of generic or broad-based technologies.[56] The program provides funding for high-risk R&D projects through a competitive process on a cost-share basis with private-company participants. ATP projects are classified in five major technology areas: biotechnology, electronics, information technology, advanced materials and chemistry, and manufacturing, and applications span from nanotechnology, health, and energy to assistive technologies.

Through FY 2004, ATP has awarded funds for 768 projects with a combined funding of $4.37 billion, about equally split between the program and its participants. The projects have involved over 1,500 participants, which include established companies and startups as well as universities and other nonprofit institutions, organized as single company efforts or joint ventures (appendix table 4-41). In FY 2004, 59 R&D projects were initiated, totaling $270 million in combined program and industry funds. The program received $177 million in FY 2004 and $140 million in FY 2005. The administration's FY 2006 budget calls for the suspension of new awards (U.S. OMB 2005).

International R&D Comparisons

Increasingly, the international competitiveness of a modern economy is defined by its ability to generate, absorb, and commercialize knowledge. Although it is no panacea, scientific and technological knowledge has proven valuable in addressing the challenges countries face in a variety of areas such as sustainable development, economic growth, health care, and agricultural production. Nations benefit from R&D performed abroad, but domestic R&D performance is an important indicator of a nation's innovative capacity and its prospects for future growth, productivity, and S&T competitiveness. This section compares international R&D spending patterns. Topics include absolute expenditure trends, measures of R&D intensity, the structure and focus of R&D performance and funding across sectors, and government research-related priorities and policies.

Most of the R&D data presented in this section are from the Organisation for Economic Co-operation and Development (OECD), the most reliable source for such international comparisons.[57] However, an increasing number of non-OECD countries and organizations now collect and publish R&D statistics, which are cited at various points in this section. No R&D-specific currency exchange rates exist, but for comparison purposes international R&D data have been converted to U.S. dollars with purchasing power parity (PPP) exchange rates (see sidebar "Comparing International R&D Expenditures").

Comparing International R&D Expenditures

If countries do not share a common currency, some conversion must be made in order to compare their R&D expenditures. Unfortunately, comparisons of international research and development statistics are hampered by the lack of R&D-specific exchange rates. The only rates consistently compiled and available for a large number of countries over an extended period of time are market exchange rates (MERs) and purchasing power parities (PPPs).

Market exchange rates. At their best, MERs represent the relative value of currencies for goods and services that are traded across borders; that is, MERs measure a currency's relative international buying power. However, MERs may not accurately reflect the true cost of goods or services that are not traded internationally. In addition, fluctuations in MERs as a result of currency speculation, political events such as wars or boycotts, and official currency intervention, which have little or nothing to do with changes in the relative prices of internationally traded goods, greatly reduce their statistical utility.

PPP exchange rates. PPPs were developed because of the MER shortcomings described above (Ward 1985). PPPs take into account the cost differences across countries of buying a similar basket of goods and services in numerous expenditure categories, including nontradables. The PPP basket is therefore assumed to be representative of total GDP across countries.

Although the goods and services included in the market basket used to calculate PPP rates differ from the major components of R&D costs (fixed assets as well as wages of scientists, engineers, and support personnel), they still result in a more suitable domestic price converter than one based on foreign trade flows. Exchange rate movements bear little relationship to changes in the cost of domestically performed R&D. The adoption of the euro as the common currency for many European countries provides a useful example: although Germany and Portugal now share a common currency, the real costs of most goods and services are substantially less in Portugal.

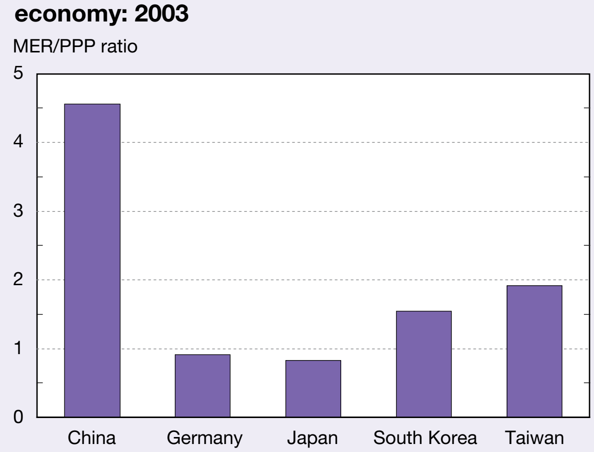
PPPs are therefore the preferred international standard for calculating cross-country R&D comparisons wherever possible and are used in all official R&D tabulations of the Organisation of Economic Co-operation and Development (OECD).

PPPs for developing economies. Because MERs tend to understate the domestic purchasing power of developing countries' currencies, PPPs can produce substantially larger R&D estimates than MERs do for these countries. For example, China's 2002 R&D expenditures are $16 billion using MERs but are $72 billion using PPPs. Figure 4-25 shows the relative difference between MERs and PPPs for a few countries.

Although PPPs are available for developing countries such as India and China, there are several reasons why they may be less useful for converting R&D expenditures than in more developed countries:

- It is difficult or impossible to assess the quality of PPPs for some countries, most notably China. Although PPP estimates for OECD countries are quite reliable, PPP estimates for developing countries are often rough approximations. The latter estimates are based on extrapolation of numbers published by the United Nations International Comparison Program and by Professors Robert Summers and Alan Heston of the University of Pennsylvania and their colleagues.
- The composition of the "market basket" used to calculate PPPs likely differs substantially between developing and developed countries. The structural differences in the economies of these countries, as well as disparities in income, may result in a market basket of goods and services in a developing country that is quite different from the market basket of a developed country, particularly as far as these baskets relate to the various costs of R&D.
- R&D performance in developing countries is often concentrated geographically in their most advanced cities and regions in terms of infrastructure and educated workforce. The costs of goods and services in these areas can be substantially greater than for the country as a whole.

Figure 4-25
Market exchange rate/purchasing power parity exchange rate ratios, selected countries/economy: 2003



MER = market exchange rate; PPP = purchasing power parity

SOURCE: Organisation for Economic Co-operation and Development, *Main Science and Technology Indicators* (2004). See appendix table 4-2.

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Figure 4-26
R&D expenditures and share of world total, by region: 2000

NOTE: R&D estimates from 80 countries in billions of purchasing power parity dollars.

SOURCES: Organisation for Economic Co-operation and Development, *Main Science and Technology Indicators* (2004); Iberoamerican Web of Science and Technology Indicators, http://www.ricyt.edu.ar, accessed 1 April 2005; and United Nations Educational, Scientific and Cultural Organization (UNESCO), Institute for Statistics, http://www.uis.unesco.org, accessed 7 April 2005. See appendix table 4-57.

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Global R&D Expenditures

Worldwide R&D performance is concentrated in a few developed nations. In 2000, global R&D expenditures totaled at least $729 billion, half of which was accounted for by the two largest countries in terms of R&D performance, the United States and Japan.[58] As figure 4-26 illustrates, over 95% of global R&D is performed in North America, Asia, and Europe. Yet even within each of these regions, a small number of countries dominate R&D performance: the United States in North America; Japan and China in Asia; and Germany, France, and the United Kingdom in Europe.

Wealthy, well-developed nations, generally represented by OECD member countries, perform most of the world's R&D, but several lesser-developed nations now report higher R&D expenditures than most OECD members. In 2000, Brazil performed an estimated $13.6 billion of R&D, roughly half the amount performed in the United Kingdom (RICYT 2004). India performed an estimated $20.0 billion in 2000, making it the seventh largest country in terms of R&D in that year, ahead of South Korea (UNESCO/UIS 2005). China was the fourth largest country in 2000 in terms of R&D performance, with $48.9 billion of R&D, only slightly less than the $50.9 billion of R&D performed in Germany (OECD 2004). In 2002, an estimated $72.0 billion of R&D was performed in China, making it the third largest country in terms of R&D performance. Given the lack of either R&D-specific exchange rates (see sidebar "Comparing International R&D Expenditures") or accepted qualitative measures of international R&D (see sidebar "Qualitative Comparisons of International R&D"), it is difficult to draw conclusions from these absolute R&D figures.

OECD and G-7 R&D Expenditures

The 30 OECD countries represented 82% of global R&D, or $602 billion, in 2000. Although global R&D estimates are not available for later years, the R&D performance of OECD countries grew to $652 billion in 2002. The G-7 countries (Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States) performed over 83% of OECD R&D in 2002. The three largest R&D performers, the United States, Japan, and Germany, account for over two-thirds of the OECD's R&D. The United States accounts for 43% of OECD R&D, a slight drop in share from 2000 when it performed 44% of all OECD R&D. Outside of the G-7 countries, South Korea is the only country that accounted for a substantial share of the OECD total (3.5% in 2002, up from 3.1% in 2000).

More money was spent on R&D activities in the United States in 2002 than in the rest of the G-7 countries combined (figure 4-27).[59] In terms of relative shares, U.S. R&D expenditures in 1984 reached historical highs of 55% of the G-7 total and 47% of the OECD total. As a proportion of the G-7 total, U.S. R&D expenditures declined steadily to a low of 48% in 1990. After the early 1990s, the U.S. percentage of

Qualitative Comparisons of International R&D

Data on R&D expenditures are often used to make international comparisons, in part because of the relative ease of comparing monetary data across countries. But although the cost of R&D in two countries can be compared, it is significantly more difficult to assess the quality of the R&D being performed in the two locations. As with other economic indicators, R&D expenditures are only proxy measures, and they do not contain all of the information policymakers and researchers need to answer their questions about science, technology, innovation, and competitiveness. In order to assess a country's R&D activities, a variety of factors could be considered in addition to quantitative data on R&D expenditures. Following are examples of factors that may relate to a country's R&D performance and innovation capabilities:

- **Culture of cooperation between sectors.** The number and quality of linkages between the various R&D-performing sectors can be used as a measure of how well a country leverages its innovation infrastructure.
- **Human capital.** The availability of a high-skilled workforce is essential for a competitive national R&D system. The ability of a country to retain its highly skilled scientists and engineers is as important as its ability to train scientists and engineers in its education system. Just as foreign companies can relocate R&D activities to lower-wage countries, mobile, skilled workers can relocate to countries with higher wages.
- **Intellectual property protection.** Strong intellectual property laws help firms to capture benefits from R&D investments. Although foreign firms may invest in R&D in countries with weak intellectual property protection, such as China and, until recently, India, the R&D performed there may be less innovative than that performed in the firms' home countries.
- **Legal restrictions on research.** Cultural pressure and government regulations can influence the nature of a country's research portfolio and be important considerations when comparing countries' R&D performance in specific fields of research.
- **Market for new technology.** The presence of a sophisticated, demanding, and wealthy domestic market can be a strong motivator for firms to invest heavily in R&D. The growth of the U.S. market for pharmaceuticals compared to Europe's is a contributing factor to the increasing attractiveness of the United States as a locus for pharmaceutical R&D. Similarly, the pervasiveness of mobile communications technology in Finnish and Japanese societies has helped these countries remain world leaders in this market.
- **Quality of research institutions.** The quality of research institutions (universities and government facilities) in a country, as defined by quantitative measures (such as publication output and number of prize-winning faculty) as well as qualitative measures (such as peer rankings), is an important factor when making international comparisons of R&D activity.
- **Research infrastructure.** Certain types of research require extremely specialized and expensive facilities and instrumentation. The availability of advanced research infrastructure and instrumentation, from radio telescopes to supercomputers, can influence the nature and quality of research performed in a country.

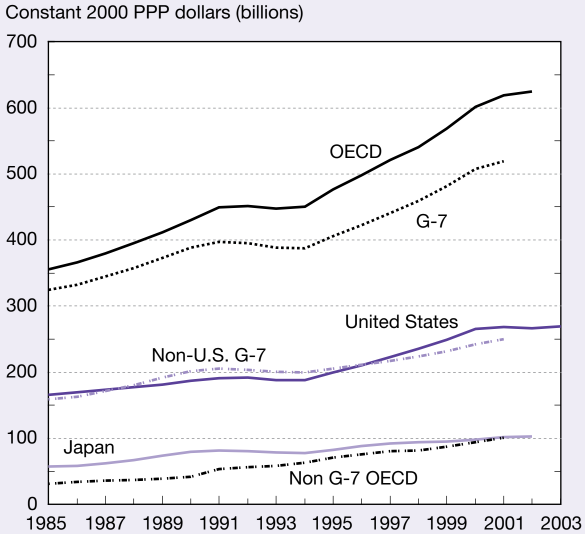
total G-7 R&D expenditures grew as a result of a worldwide slowing in R&D performance that was more pronounced in other countries. Although U.S. R&D spending idled or declined for several years in the early to mid-1990s, the reduction in real R&D spending in most of the other G-7 countries was more striking. In Japan, Germany, and Italy, inflation-adjusted R&D spending fell for 3 consecutive years (1992, 1993, and 1994) (OECD 2004).[60] R&D spending rebounded in the late 1990s in several G-7 countries, but the recovery was most robust in the United States. By 2000, the U.S. share of total G-7 R&D had grown to 52%. The subsequent slowdown in the technology market in 2001 and 2002 has had a global reach, but its impact on R&D was more pronounced in the United States than in the other G-7 countries, resulting in a decline in the U.S. share of G-7 R&D in 2001 and 2002.

Indicators of R&D Intensity

International comparisons of absolute R&D expenditures are complicated by the fact that countries vary widely in terms of the sizes of their population and economy. For example, although Germany and China had roughly equivalent R&D expenditures in 2000, China's population was over 15 times as large and its economy was over twice as large as Germany's in that year. Policymakers commonly use various measures of R&D intensity to account for these size differences when making international comparisons.

One of the first and now one of the more widely used indicators of a country's R&D intensity is the ratio of R&D spending to GDP, the main measure of a nation's total economic activity (Steelman 1947). Policymakers often use this ratio for international benchmarking and goal setting (see sidebar "European Union Strategy for R&D and Economic Competitiveness").

Figure 4-27
R&D expenditures of United States and G-7 and OECD countries: 1985–2003



OECD = Organisation for Economic Co-operation and Development; PPP = purchasing power parity

NOTE: Non-U.S. G-7 countries: Canada, France, Germany, Italy, Japan, and United Kingdom.

SOURCE: OECD, *Main Science and Technology Indicators* (2004). See appendix table 4-42.

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Normalized indicators, such as R&D/GDP ratios, are useful for international comparisons because they both account for size differences between countries and obviate the need for exchange rates. However, even normalized indicators are not always comparable from one country to another. This occurs most often when the variable being used to normalize the indicator differs across countries. For example, the structure of national economies, and hence GDP, varies greatly. As figure 4-28 shows, the agricultural and industrial sectors account for less than one-third of GDP in the United States and the other G-7 countries (Canada, France, Germany, Italy, Japan, and the United Kingdom). These sectors represent similarly small shares of the labor force. In less-developed nations, such as India and China, the agricultural and industrial sectors account for more than half of GDP and an even larger share of the labor force (estimated to be 72% in China and 77% in India) (CIA 2005). Structural differences such as this can result in significant country-to-country variation in terms of R&D indicators. For several years, economists have debated whether or not R&D should be included as part of the national accounts (see sidebar "Indicators Development on R&D Within the National Accounts: The BEA/NSF R&D Satellite Account Project").

Total R&D/GDP Ratios

The ratio of R&D expenditures to GDP is a useful indicator of the intensity of R&D activity in relation to other economic activity and can be used to gauge a nation's commitment to R&D at different points in time. In the United States, the slowdown in GDP growth in 2001 preceded the decline of U.S. R&D in 2002. This resulted in U.S. R&D to GDP ratios of 2.7% in 2001 (a recent high) and 2.6% in 2002 (figure 4-29). Following the 2002 decline, R&D grew more rapidly than GDP in the United States resulting in an R&D to GDP ratio of 2.7% in 2003.[61] The U.S. economy expanded at a faster pace in 2004, and R&D as a proportion of GDP remained at 2.7%.[62]

Since 1953, U.S. R&D expenditures as a percentage of GDP have ranged from a minimum of 1.4% (in 1953) to a maximum of 2.9% (in 1964). Most of the growth over time in the R&D/GDP ratio can be attributed to steady increases in nonfederal R&D spending.[63] Nonfederally financed R&D, the majority of which is company financed, increased from

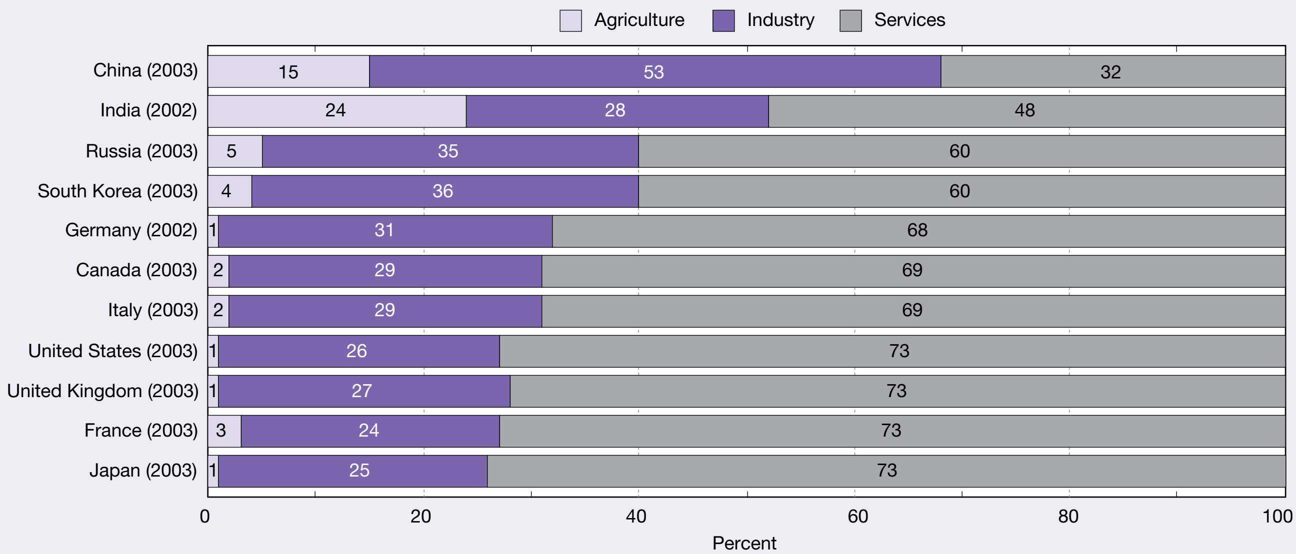
European Union Strategy for R&D and Economic Competitiveness

In March 2000, the Lisbon European Council set out a 10-year strategy to make the EU the "most competitive and dynamic knowledge-based economy in the world by 2010." A key element of the Lisbon Strategy, as it is known, is the goal to develop a more robust European Research Area. The Lisbon Strategy defined an open process of target setting and benchmarking. Each member country was expected to determine how best to achieve each target while learning from the experiences of other members.

In March 2002, the Barcelona European Council reviewed member states' progress towards the Lisbon goal. The Council determined that, to meet the goal, a target for investments in R&D equal to 3% of EU GDP must be reached by 2010, with at least two-thirds of the R&D funding coming from the private sector (a proportion similar to that of the United States). This target was set to close the large gap in R&D investment between the EU and the United States. Although two EU members (Sweden and Finland) have already met the 3% target, the EU as a whole is not on track to meet the ambitious goals set by the European Council in 2000 and 2002.

Responding to the Barcelona target in late 2002, the European Round Table of Industrialists (ERT), an association of leaders from 42 companies that represent 13% of total European R&D spending, expressed doubts as to whether either part of the R&D target was realistic. ERT noted that an internal survey of their member companies revealed few with expectations of substantially increasing their R&D investment in Europe in the coming years and concluded that "unless there is a dramatic reappraisal of Europe's approach to R&D and its framework conditions for business, the gap between the Barcelona target and the real world will not be bridged by 2010" (ERT 2002).

Figure 4-28
Composition of gross domestic product for selected countries, by sector: 2002 or 2003



SOURCE: Central Intelligence Agency, *The World Fact Book 2004*, http://www.cia.gov/cia/publications/factbook/index.html, accessed 31 March 2005.

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Indicators Development on R&D Within the National Accounts: The BEA/NSF R&D Satellite Account Project

In June 2004, the National Science Foundation (NSF) Division of Science Resources Statistics entered into a multiyear agreement with the U.S. Bureau of Economic Analysis (BEA) to produce an updated and expanded R&D satellite account by the end of FY 2007. A satellite account provides estimates of expenditures on R&D that are designed to be used in conjunction with the national income and product accounts (NIPA) measures (Carson et al. 1994). A satellite account framework recognizes the investment characteristics of R&D in terms of its role in long-term productivity and growth. According to Fraumeni and Okubo (2004), "construction of the partial R&D satellite account within a NIPA framework allows for the estimation of the impact of R&D on GDP and other macroeconomic aggregates as well as the estimation of the contribution of R&D to economic growth.…"

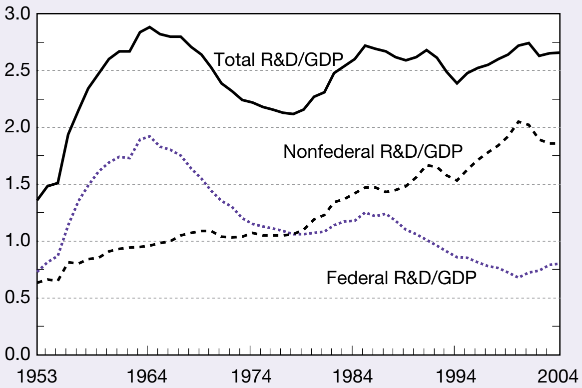
The project will include methodology to translate NSF R&D expenditure data collected based on the Frascati Manual (OECD 2002b) to gross output that is consistent with the 1993 System of National Accounts (SNA) (CEC et. al 1993; OECD 2001). The project is also expected to generate information useful in a separate effort by the OECD's Canberra Working Group on Capital Measurements, which includes the United States, studying, among other issues, the conceptual and statistical feasibility of capitalizing R&D expenditures.

0.6% of GDP in 1953 to an estimated 1.9% of GDP in 2004 (down from a high of 2.1% of GDP in 2000). The increase in nonfederally financed R&D as a percentage of GDP illustrated in figure 4-29 is indicative of the growing role of S&T in the U.S. economy.

Historically, most of the peaks and valleys in the U.S. R&D/GDP ratio can be attributed to changing priorities in federal R&D spending. The initial drop in the R&D/GDP ratio from its peak in 1964 largely reflects federal cutbacks in defense and space R&D programs. Gains in energy R&D activities between 1975 and 1979 resulted in a relative stabilization of the ratio. Beginning in the late 1980s, cuts in defense-related R&D kept federal R&D spending from keeping pace with GDP growth, whereas growth in nonfederal sources of R&D spending generally kept pace with or exceeded GDP growth. Since 2000, defense-related R&D spending has surged, and federal R&D spending growth has outpaced GDP growth. (See the discussion of defense-related R&D earlier in this chapter.)

For many of the G-8 countries (i.e., the G-7 countries plus Russia), the latest R&D/GDP ratio is no higher now than it was at the start of the 1990s, which ushered in a period of slow growth or decline in their overall R&D efforts (figure 4-30). The two exceptions, Japan and Canada, both exhibit substantial increases on this indicator between 1990 and 2002. In Japan this indicator declined in the early 1990s

Figure 4-29
R&D share of gross domestic product: 1953–2004



GDP = gross domestic product

SOURCE: National Science Foundation, Division of Science Resources Statistics, *National Patterns of R&D Resources* (annual series). See appendix tables 4-1 and 4-3.

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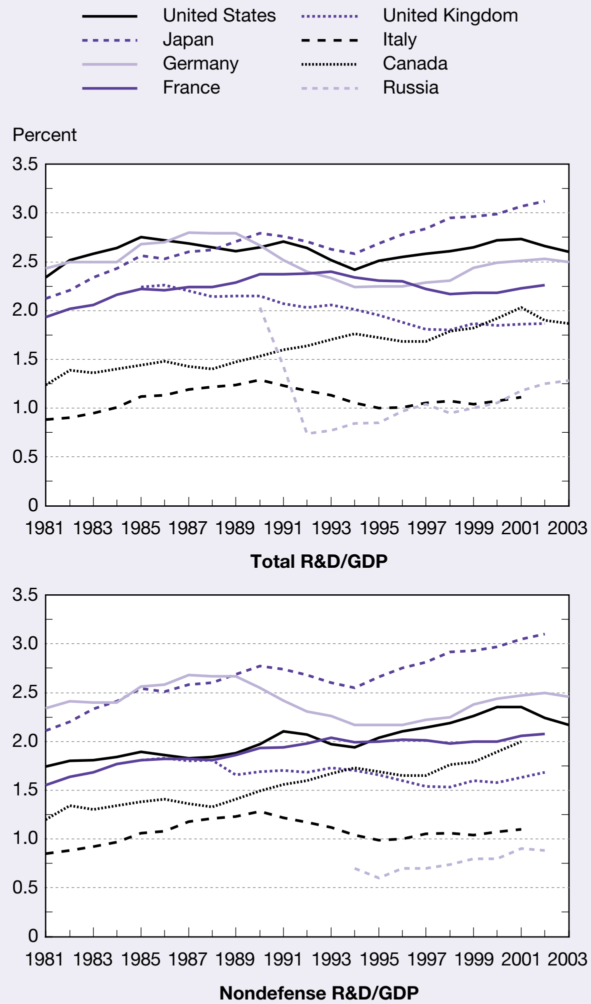
as a result of reduced or level R&D spending by industry and government, a pattern similar to that exhibited by the United States. Japan's R&D/GDP ratio subsequently rose to 3.1% in 2002, the result of a resurgence of industrial R&D in the mid-1990s coupled with anemic economic conditions. In the 5 years between 1997 and 2002, real GDP in Japan grew only 1.8%, so relatively small increases in R&D expenditures resulted in a rise in its R&D/GDP ratio.[64] By contrast, over the same period real GDP grew 21.8% in Canada; hence, the rise in its R&D/GDP ratio is more indicative of robust R&D growth.

Geopolitical events also affect R&D intensity indicators as evidenced by Germany and Russia. Germany's R&D/GDP ratio fell from 2.8% at the end of the 1980s, before reunification, to 2.2% in 1994. Its R&D/GDP has since risen to 2.5% in 2003. The end of the Cold War and collapse of the Soviet Union had a drastic effect on Russia's R&D intensity. R&D performance in Russia was estimated at 2.0% of GDP in 1990; that figure dropped to 1.4% in 1991 and then dropped further to 0.7% in 1992. The severity of this decline is compounded by the fact that Russian GDP contracted in each of these years. Both Russia's R&D and GDP exhibited strong growth after 1998. In the 5 years between 1998 and 2003, Russia's R&D doubled and its R&D/GDP ratio rose from 1.0% to 1.3%.

Overall, the United States ranked fifth among OECD countries in terms of reported R&D/GDP ratios (table 4-13), but several of its states have R&D intensities over 4%. Massachusetts, a state with an economy larger than Sweden's and twice that of Israel's, has reported an R&D intensity at or above 5% since 2001 (see the section entitled "Location of R&D Performance"). Israel (not an OECD member country), devoting 4.9% of its GDP to R&D, currently leads all countries, followed by Sweden (4.3%), Finland (3.5%), Japan (3.1%), and Iceland (3.1%). In general, nations in Southern and Eastern Europe

Figure 4-30
R&D share of gross domestic product, by selected countries: 1981–2003



GDP = gross domestic product

SOURCE: Organisation for Economic Co-operation and Development, *Main Science and Technology Indicators* (2004). See appendix tables 4-42 and 4-43.

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tend to have R&D/GDP ratios of 1.5% or lower, whereas Nordic nations and those in Western Europe report R&D spending shares greater than 1.5%. This pattern broadly reflects the wealth and level of economic development for these regions. A strong link exists between countries with high incomes that emphasize the production of high-technology goods and services and those that invest heavily in R&D activities (OECD 2000).[65] The private sector in low-income countries often has a low concentration of high-technology industries, resulting in low overall R&D spending and therefore low R&D/GDP ratios. Because of the business sector's dominant role in global R&D funding and performance, R&D/GDP ratios are most useful when comparing countries with national S&T systems of comparable maturity and development.

Table 4-13
R&D share of gross domestic product, by country/economy: selected years, 1998 and 2000–03

Country/economy	Share (%)	Country/economy	Share (%)
Total OECD (2002)	2.26	New Zealand (2001)	1.16
European Union-25 (2002)	1.86	Ireland (2001)	1.13
Israel (2003)	4.90	Italy (2001)	1.11
Sweden (2001)	4.27	Brazil (2000)	1.04
Finland (2002)	3.46	Spain (2002)	1.03
Japan (2002)	3.12	Hungary (2003)	0.95
Iceland (2002)	3.09	Portugal (2002)	0.94
United States (2003)	2.67	Turkey (2002)	0.66
South Korea (2003)	2.64	Greece (2001)	0.65
Switzerland (2000)	2.57	Cuba (2002)	0.62
Denmark (2002)	2.52	Poland (2002)	0.59
Germany (2003)	2.50	Slovak Republic (2003)	0.59
Belgium (2003)	2.33	Chile (2001)	0.57
Taiwan (2002)	2.30	Argentina (2003)	0.41
France (2002)	2.26	Panama (2001)	0.40
Austria (2003)	2.19	Costa Rica (2000)	0.39
Singapore (2002)	2.15	Mexico (2001)	0.39
Netherlands (2001)	1.88	Romania (2002)	0.38
Canada (2003)	1.87	Bolivia (2002)	0.26
United Kingdom (2002)	1.87	Uruguay (2002)	0.22
Luxembourg (2000)	1.71	Peru (2003)	0.11
Norway (2002)	1.67	Colombia (2002)	0.10
Australia (2000)	1.54	Trinidad and Tobago (2001)	0.10
Slovenia (2002)	1.53	Ecuador (1998)	0.09
Czech Republic (2003)	1.34	El Salvador (1998)	0.09
Russian Federation (2003)	1.28	Nicaragua (2002)	0.07
China (2002)	1.22		

OECD = Organisation for Economic Co-operation and Development

NOTES: Civilian R&D only for Israel and Taiwan. Data for latest available year in parentheses.

SOURCES: National Science Foundation, Division of Science Resources Statistics, *National Patterns of R&D Resources* (annual series); OECD, *Main Science and Technology Indicators* (2004); and Iberoamerican Network of Science and Technology Indicators, http://www.ricyt.edu.ar, accessed 1 May 2005.

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Outside the European region, R&D spending has intensified considerably since the early 1990s. Several Asian countries, most notably South Korea and China, have been particularly aggressive in expanding their support for R&D and S&T-based development. In Latin America and the Pacific region, other non-OECD countries also have attempted to increase R&D investments substantially during the past several years. Even with recent gains, however, most non-European (non-OECD) countries invest a smaller share of their economic output in R&D than do OECD members (with the exception of Israel). All Latin American countries for which such data are available report R&D/GDP ratios at or below 1% (table 4-13). This distribution is consistent with broader indicators of economic growth and wealth.

Nondefense R&D Expenditures and R&D/GDP Ratios

Another indicator of R&D intensity, the ratio of nondefense R&D to GDP, is useful when comparing nations with different financial investments in national defense. Although defense-related R&D does result in spillovers that produce social benefits, nondefense R&D is more directly oriented toward national scientific progress, standard-of-living improvements, economic competitiveness, and commercialization of research results. Using this indicator, the relative position of the United States falls below that of Germany and just above France among the G-7 nations (figure 4-30). This is because the United States devotes more of its R&D to defense-related activities than most other countries. In 2002 approximately 16% of U.S. R&D was defense related, whereas less then 1% of the R&D performed in Germany and Japan was defense related. Both of these countries rely heavily on international alliances for national defense. Approximately 10% of the United Kingdom's total R&D was defense related in 2002.

Since the end of the Cold War, the relative share of defense-related R&D has diminished markedly in several countries. Between 1988 and 2002, the defense share of R&D fell from 31% to 16% in the United States and from 19% to 8% in France. Between 1989 and 2002, the defense share of R&D fell from 23% to 10% in the United Kingdom. The defense-related share of R&D is higher in Russia (30% in 2002), where, unlike in the G-7 countries, the government funds the majority of national R&D (see the section entitled "International R&D by Performer and Source of Funds").

Basic Research/GDP Ratios

R&D involves a wide range of activities, ranging from basic research to the development of marketable goods and services. Basic research generally has low short-term returns, but it builds intellectual capital and lays the groundwork for future advances in S&T. The relative investment in basic research as a share of GDP therefore indicates differences in national priorities, traditions, and incentive structures with respect to S&T. Estimates of basic research often involve a greater element of subjective assessment than other R&D indicators; thus, only half of the OECD member countries report these data at the national level. Nonetheless, where these data exist, they help differentiate the national innovation systems of different countries in terms of how their R&D resources contribute to advancing scientific knowledge and developing new technologies.

High basic research/GDP ratios generally reflect the presence of robust academic research centers in the country and/or a concentration of high-technology industries (such as biotechnology) with patterns of strong investment in basic research (see "International R&D by Performer and Source of Funds"). Of the OECD countries for which data are available, Switzerland has the highest basic research/GDP ratio at 0.7% (figure 4-31). This is significantly higher than either the U.S. ratio of 0.5% or the Japanese ratio of 0.4%. Switzerland, a small high-income country boasting the highest number of Nobel prizes, patents, and science citations per capita worldwide, devoted more than 60% of its R&D to basic and applied research in 2000 despite having an industrial R&D share (74%) comparable to the United States and Japan. The differences among the Swiss, U.S., and Japanese character-of-work shares reflect both the high concentration of chemical and pharmaceutical R&D in Swiss industrial R&D as well as the "niche strategy" of focusing on specialty products adopted by many Swiss high-technology industries.

China, despite its growing investment in R&D, reports among the lowest basic research/GDP ratios (0.07%), below Argentina (0.10%) and Mexico (0.12%) (figure 4-32). With its emphasis on applied research and development aimed at

Figure 4-31
Basic research share of gross domestic product, by country/economy: Selected years, 2000–02

GDP = gross domestic product

NOTE: Data are for years in parentheses.

SOURCE: Organisation for Economic Co-operation and Development, *Main Science and Technology Indicators* (2004).

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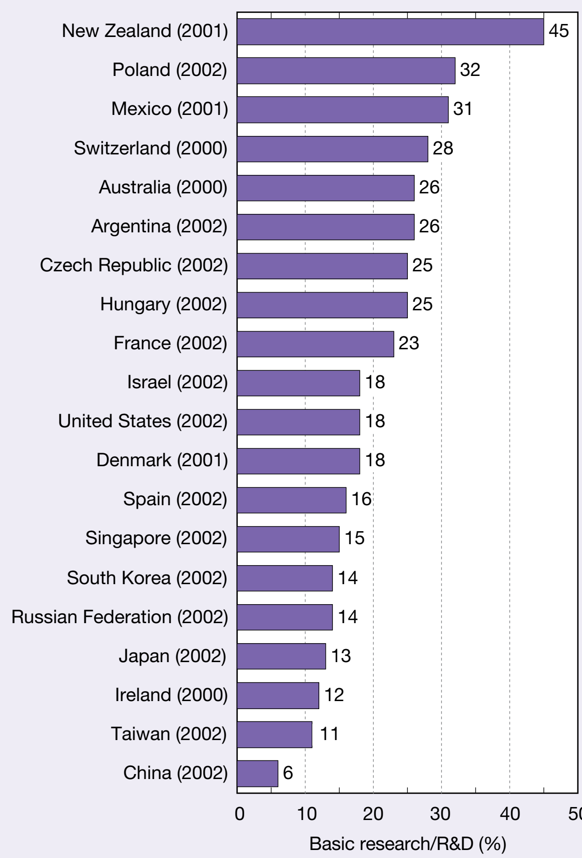
Figure 4-32
Basic research share of R&D, by country/economy: Selected years, 2000–02



NOTE: Data are for years in parentheses.

SOURCE: Organisation for Economic Co-operation and Development, *Main Science and Technology Indicators* (2004).

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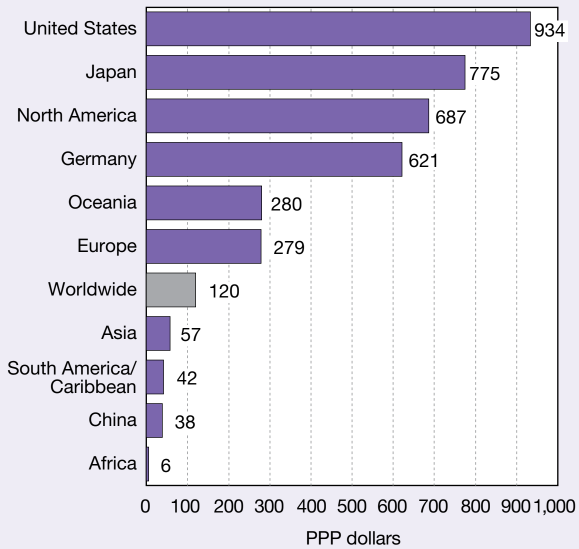
Figure 4-33
R&D expenditures per capita, by country/region: 2000



PPP = purchasing power parity

NOTE: R&D estimates from 80 countries.

SOURCES: Organisation for Economic Co-operation and Development, *Main Science and Technology Indicators* (2004); Iberoamerican Web of Science and Technology Indicators, http://www.ricyt.edu.ar, accessed 1 April 2005; United Nations Educational, Scientific, and Cultural Organization (UNESCO) Institute for Statistics, http://www.uis.unesco.org, accessed 7 April 2005; and United Nations Population Division, Department of Economic and Social Affairs, *World Population Prospects: The 2004 Revision,* http://esa.un.org/unpp, and *World Urbanization Prospects: The 2003 Revision,* http://www.un.org/esa/population/publications/wup2003/2003WUP.htm, accessed 9 April 2005. See appendix table 4-57.

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short-term economic development, China follows the pattern set by Taiwan, Singapore, South Korea, and Japan. In each of these countries or economies, basic research accounts for 15% or less of total R&D.

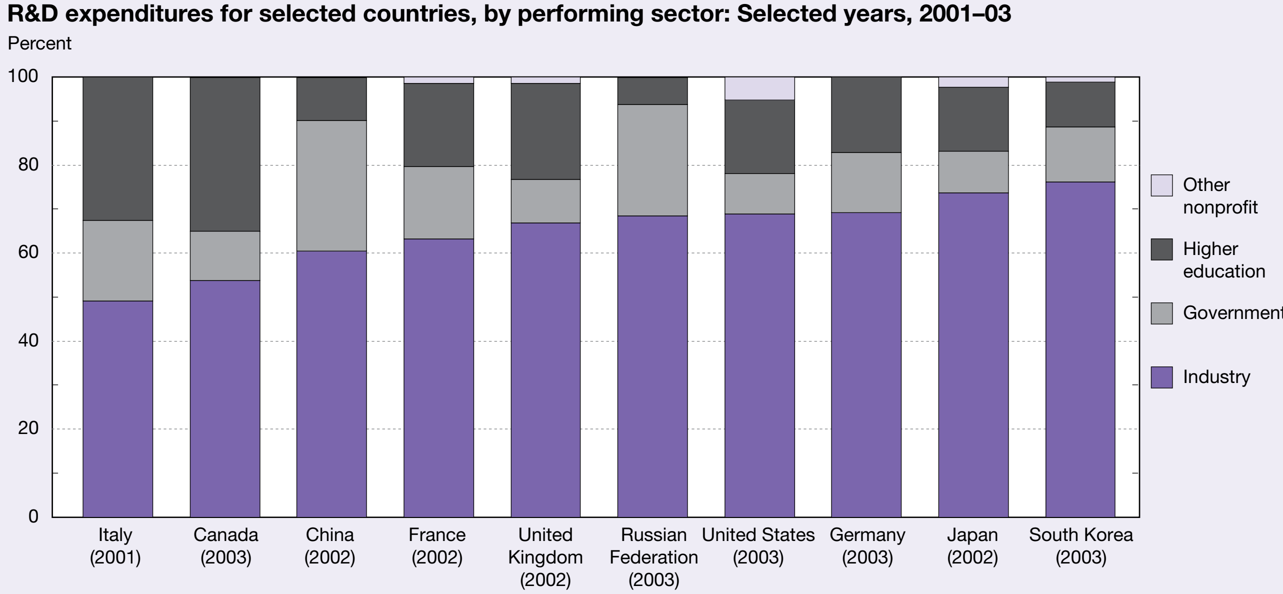
R&D per Capita

Although R&D as a percentage of GDP is the most commonly used indicator for international comparisons of S&T, regional differences in R&D intensity are even more pronounced using the indicator of R&D expenditures per capita (figure 4-33). Although China and Germany reported similar R&D expenditures in 2000, on a per capita basis Germany's R&D was over 16 times China's. Because the salaries of scientists and engineers are a large component of R&D expenditures, high R&D per capita is proportionate both to the relative number of researchers working in a country as well as the wages these researchers are earning. Regions with a concentration of wealthy countries, such as North America and Europe, far outstrip lesser-developed regions such as Africa and South America on both of these measures.

International R&D by Performer and Source of Funds

R&D performance patterns by sector are broadly similar across countries, but national sources of support differ considerably. In each of the G-8 countries the industrial sector is the largest performer of R&D (figure 4-34). Industry's share of R&D performance ranged from 49% in Italy to over 73% in Japan and South Korea; it was 69% in the United States. In most countries industrial R&D is financed primarily by the business sector. A notable exception is the Russian Federation, where

Figure 4-34
R&D expenditures for selected countries, by performing sector: Selected years, 2001–03



NOTES: Data are for years in parentheses.

SOURCES: Organisation for Economic Co-operation and Development, *Main Science and Technology Indicators* (2004). See appendix table 4-44.

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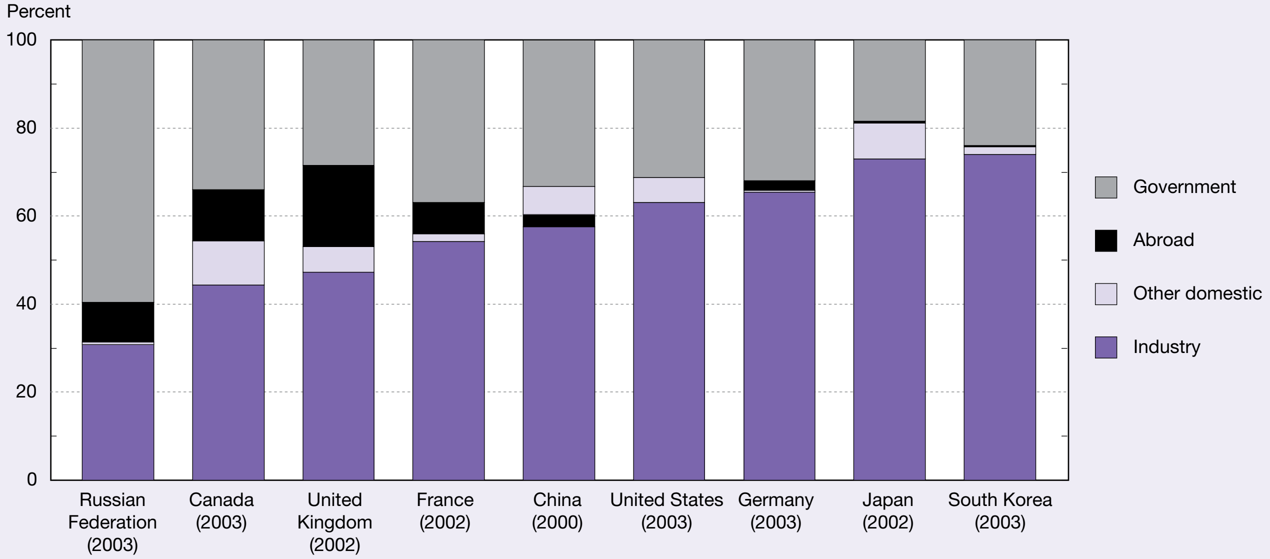
Figure 4-35
R&D expenditures for selected countries, by source of funds: Selected years, 2000–03



NOTES: Data are for years in parentheses. Separate data on foreign sources of R&D funding unavailable for United States but included in sector totals. In most other countries, "foreign sources of funding" is a distinct and separate funding category. For some countries (such as Canada), foreign firms are source of a large amount of foreign R&D funding, reported as funding from abroad. In United States, industrial R&D funding from foreign firms reported as industry. Data unavailable for Italy.

SOURCES: Organisation for Economic Co-operation and Development, *Main Science and Technology Indicators* (2004). See appendix table 4-44.

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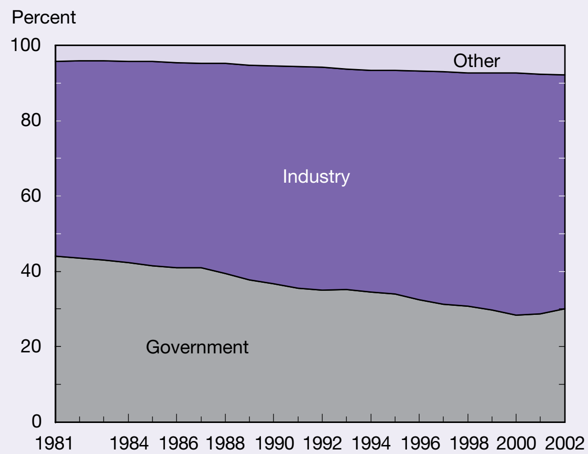
government was the largest source of industrial R&D funding in 2001 (NSB 2004).

In all of the G-8 countries except Russia, the academic sector was the second largest R&D performer (representing from 15% to 35% of R&D performance in each country). In Russia, government is the second largest R&D performer, accounting for 25% of its R&D performance in 2003. Government-performed R&D is even more prominent in China, where it accounted for an estimated 30% of Chinese R&D performance in 2002.

Government and industry together account for over three-quarters of the R&D funding in each of the G-8 countries, although their respective contributions vary (figure 4-35).[66] Among these countries the industrial sector provided as much as 73% of R&D funding in Japan to as little as 31% in Russia. Government provided the largest share of Russia's R&D (60%), as it has in Italy in past years (more than 50% in 1999). In the remaining six G-8 member nations, government was the second largest source of R&D funding, ranging from 19% of total R&D funding in Japan to 37% in France.

In nearly all OECD countries, the government's share of total R&D funding has declined over the past two decades, as the role of the private sector in R&D grew considerably (figure 4-36). In 2002, 30% of all R&D funds were derived from government sources, down from 44% in 1981.[67] The relative decline of government R&D funding is the result of budgetary constraints, economic pressures, and changing priorities in government funding (especially the relative reduction in defense R&D in several of the major R&D-performing countries, notably France, the United Kingdom, and the United States). This trend also reflects the absolute growth in industrial R&D funding, irrespective of government R&D spending patterns.

Figure 4-36
Total OECD R&D, by source of funds: 1981–2002



OECD = Organisation for Economic Co-operation and Development

SOURCE: OECD, *Main Science and Technology Indicators* (2004). See appendix table 4-46.

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Canada and the United Kingdom both report relatively large amounts of R&D funding from abroad (12% and 18%, respectively), much of which originates from foreign business enterprises (figure 4-35). Businesses in the United States also receive foreign R&D funding; however, these data are not separately reported in U.S. R&D statistics and are included in the figures reported for industry. Therefore the industry share of R&D funding for the United States is overstated compared with the industry shares for countries where foreign sources of R&D funding are reported separately from domestic sources (see "Industrial Sector"). In the United States companies include foreign sources of R&D funding in the category "company and other nonfederal sources" when responding to the U.S. Survey of Industrial R&D.

Industrial Sector

The structure of industrial R&D varies substantially among countries in terms of both sector concentration and sources of funding. Because industrial firms account for the largest share of total R&D performance in each of the G-8 countries and most OECD countries, differences in industrial structure can help explain international differences in more aggregated statistics such as R&D/GDP. For example, countries with higher concentrations of R&D-intensive industries (such as communications equipment manufacturing) are likely to also have higher R&D/GDP ratios than countries whose industrial structures are weighted more heavily toward less R&D-intensive industries.

Sector Focus

Using internationally comparable data, in 2002 no one industry accounted for more than 11% of total business R&D in the United States (figure 4-37; appendix table 4-58). This is largely a result of the size of business R&D expenditures in the United States, which makes it difficult for any one sector to dominate. However, the diversity of R&D investment by industry in the United States is also an indicator of how the nation's accumulated stock of knowledge and well-developed S&T infrastructure have made it a popular location for R&D performance in a broad range of industries.

Compared with the United States, many of the other countries shown in figure 4-37 display much higher industry and sector concentrations. In countries with less business R&D, high sector concentrations can result from the activities of one or two large companies. This pattern is notable in Finland, where the radio, television, and communications equipment industry accounted for almost half of business R&D in 2002. This high concentration likely reflects the activities of one company, Nokia, the world's largest manufacturer of cellular phones (see also table 4-6 in sidebar "R&D Expenses of Public Corporations"). By contrast, South Korea's high concentration (46% of business R&D in 2003) of R&D in this industry is not the result of any one or two companies, but reflects the structure of its export-oriented economy. South Korea is one of the world's top producers of electronic goods, and its top two export commodities are semiconductors and cellular phones (see sidebar "R&D in the ICT Sector").

Other industries also exhibit relatively high concentrations of R&D by country. Automotive manufacturers rank among the largest R&D-performing companies in the world (see sidebar "R&D Expenses of Public Corporations"). Because of this, the countries that are home to the world's major automakers also boast the highest concentration of R&D in the motor vehicles industry. This industry accounts for 29% of Germany's business R&D, 27% of the Czech Republic's, and 19% of Sweden's, reflecting the operations of automakers such as DaimlerChrysler and Volkswagen in Germany, Skoda in the Czech Republic, and Volvo and Saab in Sweden. Japan, France, South Korea, and Italy are also home to large R&D-performing firms in this industry.

The pharmaceuticals industry is less geographically concentrated than the automotive industry, but is still prominent in several countries. The pharmaceuticals industry accounts for over 20% of business R&D in the United Kingdom, Belgium, and Denmark. The United Kingdom is the largest performer of pharmaceutical R&D in Europe and is home to GlaxoSmithKline, the second largest pharmaceutical company in the world in terms of R&D expenses in 2002 and 2003 (table 4-6).

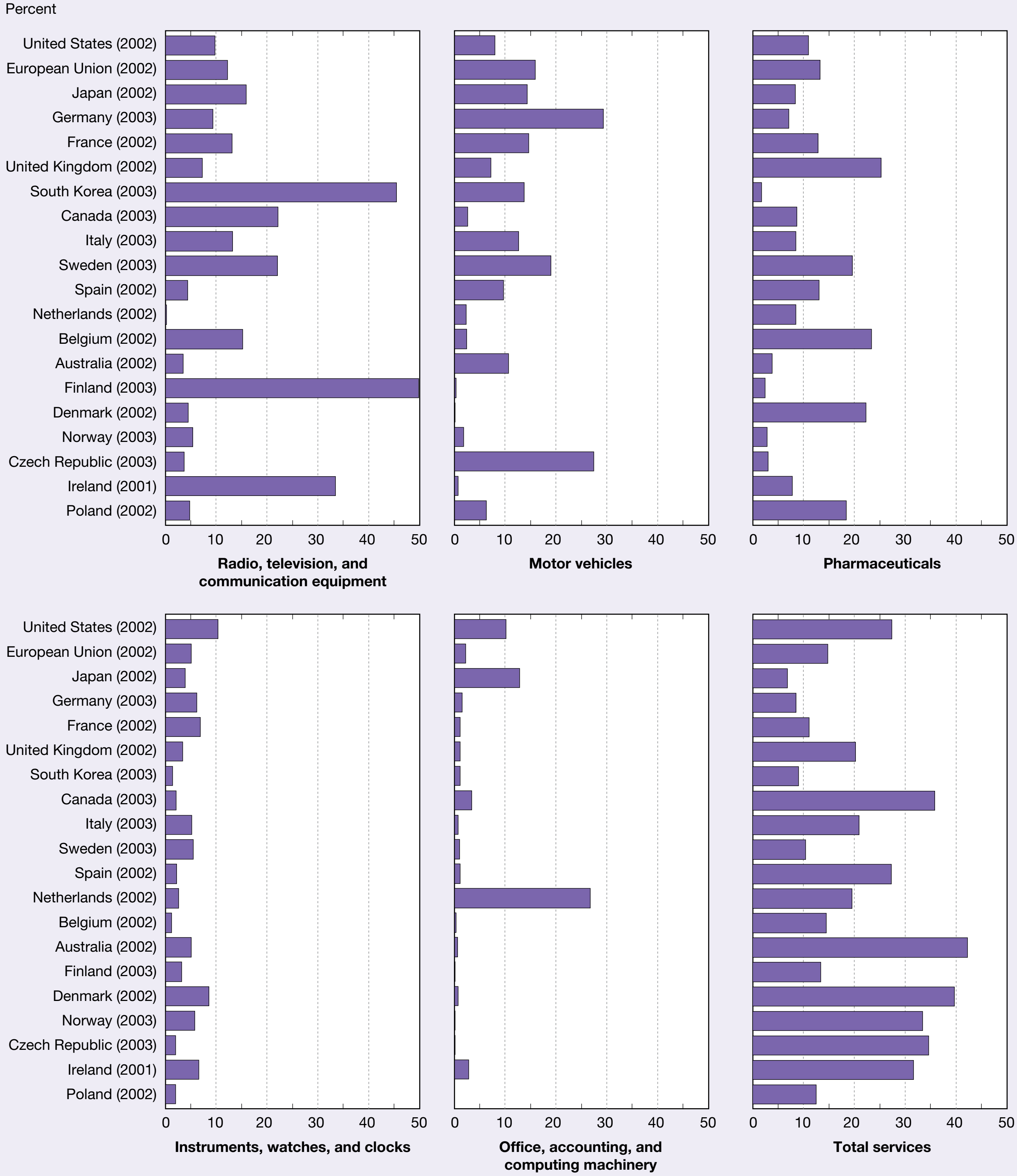
The office, accounting, and computing machinery industry represents only a small share of business R&D in most countries, with the United States and Japan accounting for over 90% of this industry's R&D among OECD countries (appendix table 4-58). Only the Netherlands reports a high concentration of business R&D in this industry (27% in 2002), most likely representing the activities of Royal Philips Electronics, the largest electronics company in Europe.

One of the more significant trends in both U.S. and international industrial R&D activity has been the growth of R&D in the service sector. In the European Union (EU), service-sector R&D has grown from representing 8% of business R&D in 1992 to 15% in 2002 (figure 4-40). In 2002, the EU's service-sector R&D nearly equaled that of its motor vehicles industry and more than doubled that of its aerospace industry. According to national statistics for recent years, the service sector accounted for less than 10% of total industrial R&D performance in only three of the countries shown in figure 4-37 (Germany, South Korea, and Japan). Among the countries listed in figure 4-37, the service sector accounted for as little as 7% of business R&D in Japan to as much as 42% in Australia, and it accounted for 27% of total business R&D in the United States.[68] Information and communications technologies (ICT) services account for a substantial share of the service R&D totals (see sidebar "R&D in the ICT Sector").

Sources of Industrial R&D Funding

Most of the funding for industrial R&D in each of the G-8 countries is provided by the business sector. In most OECD countries government financing accounts for a small and declining share of total industrial R&D performance (figure 4-41). In 1981, government provided 22% of the funds used by industry in conducting R&D within OECD countries,

Figure 4-37
Share of industrial R&D, by industry sector and selected country/European Union: Selected years, 2001–03



NOTES: Countries listed in descending order by amount of total industrial R&D. Data for years in parentheses.

SOURCE: Organisation for Economic Co-operation and Development, ANBERD database, http://www1.oecd.org/dsti/sti/stat-ana/stats/eas_anb.htm (2004). See appendix table 4-58.

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R&D in the ICT Sector

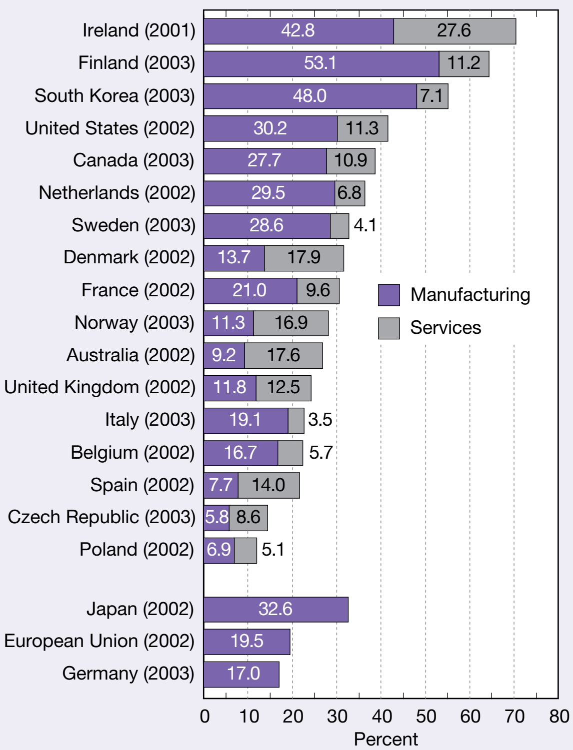
Information and communications technologies (ICTs) play an increasingly important role in the economies of Organisation for Economic Co-operation and Development (OECD) member countries. Both the production and use of these technologies contribute to output and productivity growth. Compared with other industries, ICT industries are among the most research and development intensive, with their products and services embodying increasingly complex technology. Because R&D data are often unavailable for detailed industries, for the purpose of this analysis ICT industries include the following ISIC (International Standard Industrial Classification) categories:

- ♦ Manufacturing industries: 30 (office, accounting, and computer machinery), 32 (radio, television, and communications equipment), and 33 (instruments, watches, and clocks)
- ♦ Services industries: 64 (post and communications) and 72 (computer and related activities) (OECD 2002a)

The ICT sector accounted for over one-quarter of total business R&D in 12 of the 20 OECD countries shown in figure 4-38, and more than half of total business R&D in Ireland, Finland, and South Korea. ICT industries accounted for 42% of the business R&D in the United States and at least 33% of Japanese business R&D. Of the other G-7 countries, Canada comes closest to matching the ICT R&D concentration of the United States and Japan.

Although the U.S. concentration of R&D in manufacturing ICT industries was much lower than in several other OECD member countries, the United States still accounted for 49% of all OECD-wide R&D expenditures in ICT manufacturing in 2002 (figure 4-39). Japan and South Korea, which have historically emphasized ICT manufacturing, together accounted for 29% of the total, with the larger OECD members making up the bulk of the remainder.

Figure 4-38
Industrial R&D, by information and communications technologies sector, by selected country/European Union: Selected years, 2001–03



NOTE: Data are for years in parentheses. Information and communications technologies service-sector R&D data not available for European Union, Germany, and Japan.

SOURCE: Organisation for Economic Co-operation and Development, ANBERD database, http://www1.oecd.org/dsti/sti/stat-ana/stats/eas_anb.htm (March 2005).

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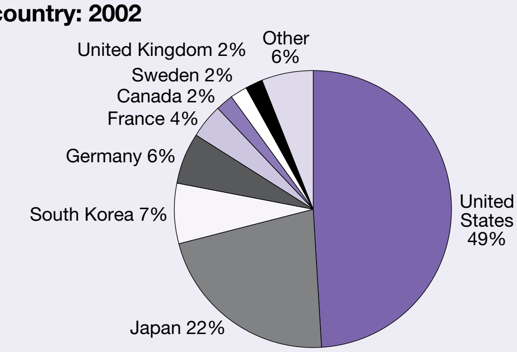
Figure 4-39
OECD-wide information and communications technologies manufacturing R&D, by selected country: 2002



OECD = Organisation for Economic Co-operation and Development

NOTE: Figure based on only 19 OECD countries. Data for Germany are for 2001.

SOURCE: OECD, ANBERD database, http://www1.oecd.org/dsti/sti/stat-ana/stats/eas_anb.htm (March 2005).

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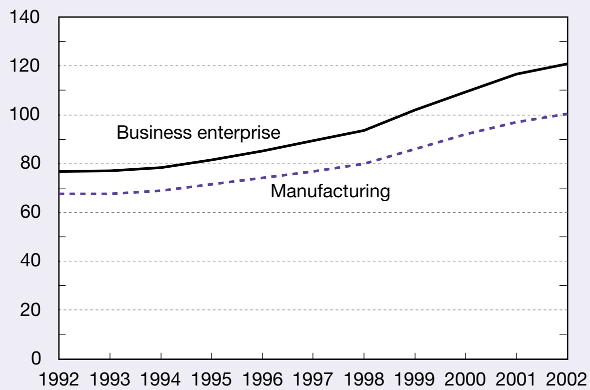
whereas, by 2002, government's funding share of industrial R&D had fallen to 7%. Among G-7 countries, government financing shares ranged from as little as 1% of industrial R&D performance in Japan in 2002 to 14% in Italy in 2003 (appendix table 4-44). In the United States in 2003, the federal government provided about 10% of the R&D funds used by industry, and the majority of that funding was obtained through DOD contracts.

Foreign sources of funding for business R&D increased in many countries between 1981 and 2003 (figure 4-42). The role of foreign funding varied from country to country, accounting for less than 1% of industrial R&D in Japan

Figure 4-40
European Union industrial R&D performance: 1992–2002



PPP = purchasing power parity

SOURCE: Organisation for Economic Co-operation and Development, ANBERD database, http://www1.oecd.org/dsti/sti/stat-ana/stats/eas_anb.htm (2004).

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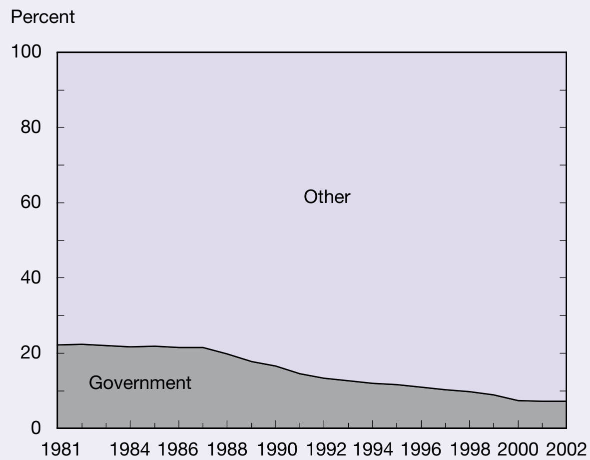
Figure 4-41
OECD industry R&D, by source of funds: 1981–2002



OECD = Organisation for Economic Co-operation and Development

SOURCE: OECD, *Main Science and Technology Indicators* (2004). See appendix table 4-46.

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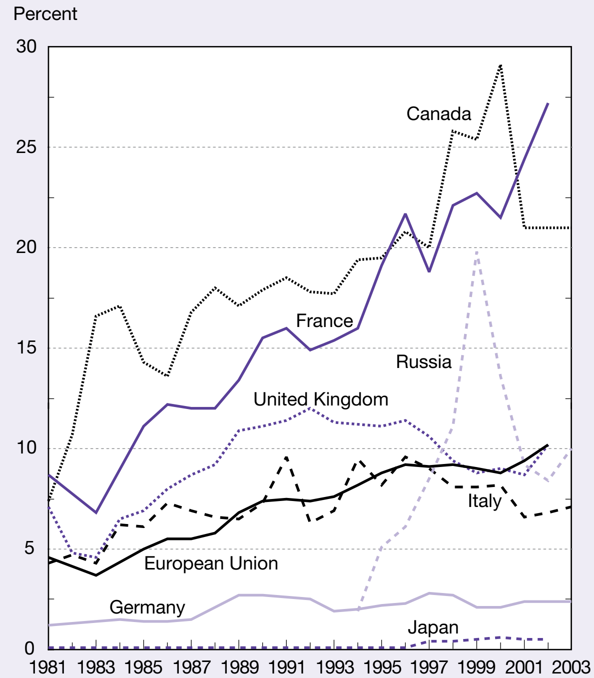
to as much as 29% in Canada in 2000. This foreign funding predominantly came from foreign corporations but also included funding from foreign governments and other foreign organizations. The growth of this funding primarily reflects the increasing globalization of industrial R&D activities. For European countries, however, the growth in foreign sources of R&D funds may also reflect the expansion of coordinated European Community efforts to foster cooperative shared-cost research through its European Framework Programmes.[69] Although the pattern of foreign funding has seldom been smooth

Figure 4-42
Industrial R&D financed, by foreign sources: 1981–2003



NOTE: Data not available for all countries for all years.

SOURCE: Organisation for Economic Co-operation and Development, *Main Science and Technology Indicators* (2004). See appendix table 4-45.

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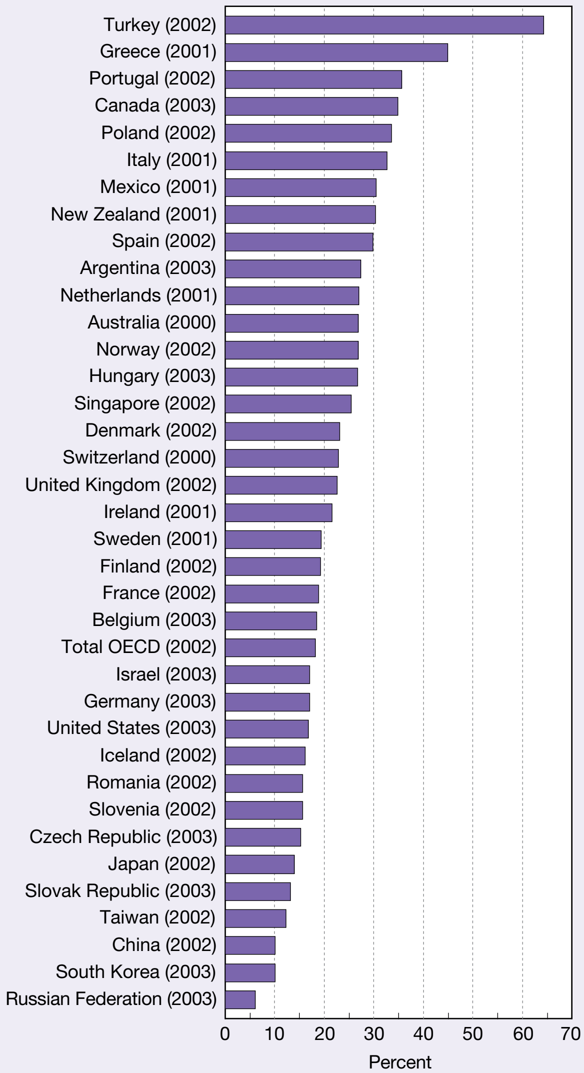
over time, it accounted for more than 20% of industry's domestic performance totals in Canada from 1996 to 2003 and in the United Kingdom from 1998 to 2002. Foreign funding as a share of Russian industrial R&D grew rapidly from 2% in 1994 to 20% in 1999, but it has since fallen to 10% in 2003. There are no data on foreign funding sources of U.S. R&D performance. However, the importance of international investment for U.S. R&D is highlighted by the fact that approximately 14% of funds spent on industrial R&D performance in 2002 were estimated to have come from majority-owned affiliates of foreign firms investing domestically (see figure 4-46 in "R&D Investments by Multinational Corporations").

Academic Sector

In many OECD countries, the academic sector is a distant second to industry in terms of national R&D performance. Among G-8 countries, universities accounted for as little as 6% of total R&D in Russia to as much as 35% in Canada; they accounted for 17% of U.S. total R&D (figure 4-43).[70] The academic sector plays a relatively small role in the national R&D of the largest Asian R&D-performing countries, accounting for 14% or less of R&D in Japan, China, South Korea, and Taiwan. Each of these countries also reports relatively low

Figure 4-43
Academic R&D share of total R&D, by selected country/economy or OECD: Selected years, 2000–03



OECD = Organisation for Economic Co-operation and Development

NOTE: Data are for years in parentheses.

SOURCE: OECD, *Main Science and Technology Indicators* (2004).

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amounts of basic research as a share of total R&D (figure 4-32). The relative size of the academic sector's R&D in a country tends to correlate with the basic research share reported by that country because academic R&D is usually more focused on basic research than industry R&D.

Source of Funds

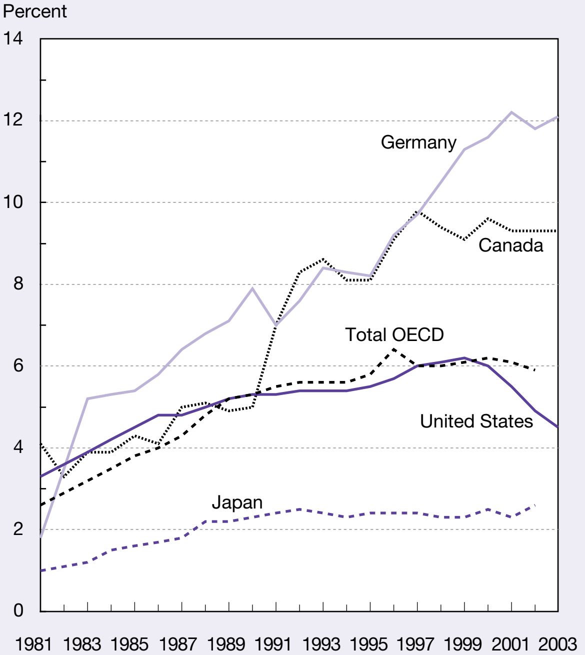
For most countries, the government is now, and historically has been, the largest source of academic research funding (see sidebar "Government Funding Mechanisms for Academic Research"). However, in each of the G-7 countries for which historical data exist, the government's share has declined since 1981, and industry's share has increased. This trend has been most evident in Germany, where the industry-funded share of academic R&D is twice that of all OECD members combined, and in Canada (figure 4-44).

Government Funding Mechanisms for Academic Research

Because U.S. universities generally do not maintain data on departmental research, U.S. totals are understated relative to the R&D effort reported for other countries. The national totals for Europe, Canada, and Japan include the research component of general university fund (GUF) block grants provided by all levels of government to the academic sector. These funds can support departmental R&D programs that are not separately budgeted. The U.S. federal government does not provide research support through a GUF equivalent, preferring instead to support specific, separately budgeted R&D projects. However, some state government funding probably does support departmental research at public universities in the United States.

Whereas GUF block grants are reported separately for Japan, Canada, and European countries, the United States does not have an equivalent GUF category. In the United States, funds to the university sector are distributed to address the objectives of the federal agencies that provide the R&D funds. Nor is GUF equivalent to basic research. The treatment of GUF is one of the major areas of difficulty in making international R&D comparisons. In many countries, 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 GUF is included in national R&D statistics, but problems arise in identifying the amount of the R&D component and the objective of the research. Government GUF support is in addition to support provided in the form of earmarked, directed, or project-specific grants and contracts (funds for which 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 are national governments in Europe and elsewhere. In each of the European G-7 countries, GUF accounts for 50% or more of total government R&D to universities and for roughly 45% of the Canadian government academic R&D support. These data indicate not only relative international funding priorities but also funding mechanisms and philosophies regarding the best methods for financing academic research.

Figure 4-44
Academic R&D financed by industry, by selected country/OECD: 1981–2003



OECD = Organisation for Economic Co-operation and Development

SOURCE: OECD, *Main Science and Technology Indicators* (2004). See appendix table 4-46.

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Industry's share of academic R&D funding is greatest in Russia (28% in 2003) and China (32% in 2000).

S&E Fields

Most countries supporting a substantial level of academic R&D (at least $1 billion PPPs in 1999) devote a larger proportion of their R&D to engineering and social sciences than does the United States (table 4-14). Conversely, the U.S. academic R&D effort emphasizes the medical sciences and natural sciences relatively more than do many other OECD countries.[71] The latter observation is consistent with the emphases in health and biomedical sciences for which the United States (and in particular NIH and U.S. pharmaceutical companies) is known.

Government R&D Priorities

Analyzing public expenditures for R&D by major socioeconomic objectives shows how government priorities differ considerably across countries and change over time.[72] Within the OECD, the defense share of governments' R&D financing declined from 43% in 1986 to 29% in 2001 (table 4-15). Much of this decline was driven by the United States, where the defense share of the government's R&D budget dropped from 69% in 1986 to 50% in 2001. The defense share of the U.S. government's R&D budget is projected to have grown to 57% in 2005 ($75 billion).

Notable shifts also occurred in the composition of OECD countries' governmental nondefense R&D support over the

Table 4-14
Share of academic R&D expenditures, by country and S&E field: Selected years, 2000–02
(Percent distribution)

Field	United States (2001)	Japan (2002)	Germany (2001)	Spain (2002)	Netherlands (2001)	Australia (2000)	Sweden (2001)	Switzerland (2002)
Academic R&D expenditure								
(2000 PPP $ billions)	32.0	14.3	8.5	2.6	2.2	2.1	2.0	1.4
Academic R&D	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NS&E	93.8	68.1	78.2	78.2	73.2	73.3	77.8	47.6
Natural sciences	40.4	11.7	29.2	37.7	17.8	25.9	18.4	19.9
Engineering	15.3	25.5	19.7	22.6	22.3	16.0	25.5	9.8
Medical sciences	31.1	26.7	25.1	12.3	27.7	24.1	28.6	17.9
Agricultural sciences	7.1	4.3	4.1	5.5	5.5	7.4	5.3	NA
Social sciences and humanities	NA	31.9	20.9	21.8	23.6	26.7	19.1	14.7
Social sciences	6.2	NA	8.6	14.7	NA	19.8	13.1	NA
Humanities	NA	NA	12.3	7.1	NA	6.9	6.0	NA
Academic NS&E								
NS&E	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Natural sciences	43.0	17.1	37.4	48.3	24.3	35.3	23.6	41.8
Engineering	16.3	37.4	25.2	28.9	30.4	21.8	32.8	20.5
Medical sciences	33.1	39.2	32.1	15.8	37.9	32.8	36.8	37.6
Agricultural sciences	7.5	6.3	5.3	7.0	7.5	10.1	6.8	NA

NA = detail not available but included in totals
NS&E = natural sciences and engineering; PPP = purchasing power parity

NOTES: Detail may not add to total because of rounding. Data for years in parentheses.

SOURCES: Organisation for Economic Co-operation and Development, Science and Technology Statistics database (2005).

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Table 4-15
Government R&D support for defense and nondefense purposes, all OECD countries: 1981–2001
(Percent)

			Nondefense R&D budget shares			
Year	Defense	Nondefense	Health and environment	Economic development programs	Civil space	Other purposes
1981	34.6	65.4	19.2	37.6	9.6	33.6
1982	36.9	63.1	18.9	37.8	8.3	35.0
1983	38.7	61.3	18.8	36.9	7.5	36.8
1984	40.8	59.2	19.6	36.1	7.8	36.6
1985	42.4	57.6	20.0	35.8	8.4	35.8
1986	43.4	56.6	20.0	34.7	8.6	36.8
1987	43.2	56.8	20.8	32.5	9.6	37.1
1988	42.6	57.5	21.1	30.8	10.0	38.1
1989	41.2	58.8	21.4	29.9	10.8	37.9
1990	39.3	60.8	21.8	28.8	11.7	37.8
1991	36.3	63.7	21.7	28.1	11.8	38.4
1992	35.3	64.7	22.0	27.0	11.9	39.1
1993	35.2	64.8	22.0	26.1	12.1	39.8
1994	32.9	67.1	22.2	25.1	12.3	40.3
1995	31.2	68.8	22.5	24.4	12.1	41.0
1996	30.9	69.1	22.6	24.4	11.9	41.1
1997	30.8	69.2	22.9	24.6	11.4	41.1
1998	30.0	70.0	23.6	22.8	11.4	42.3
1999	29.4	70.6	24.5	23.3	10.7	41.6
2000	28.3	71.7	24.5	21.8	10.0	43.8
2001	28.6	71.4	26.2	22.1	10.0	41.6

OECD = Organisation for Economic Co-operation and Development

NOTE: Nondefense R&D classified as other purposes consists largely of general university funds and nonoriented research programs.

SOURCE: OECD, *Main Science and Technology Indicators* (2004).

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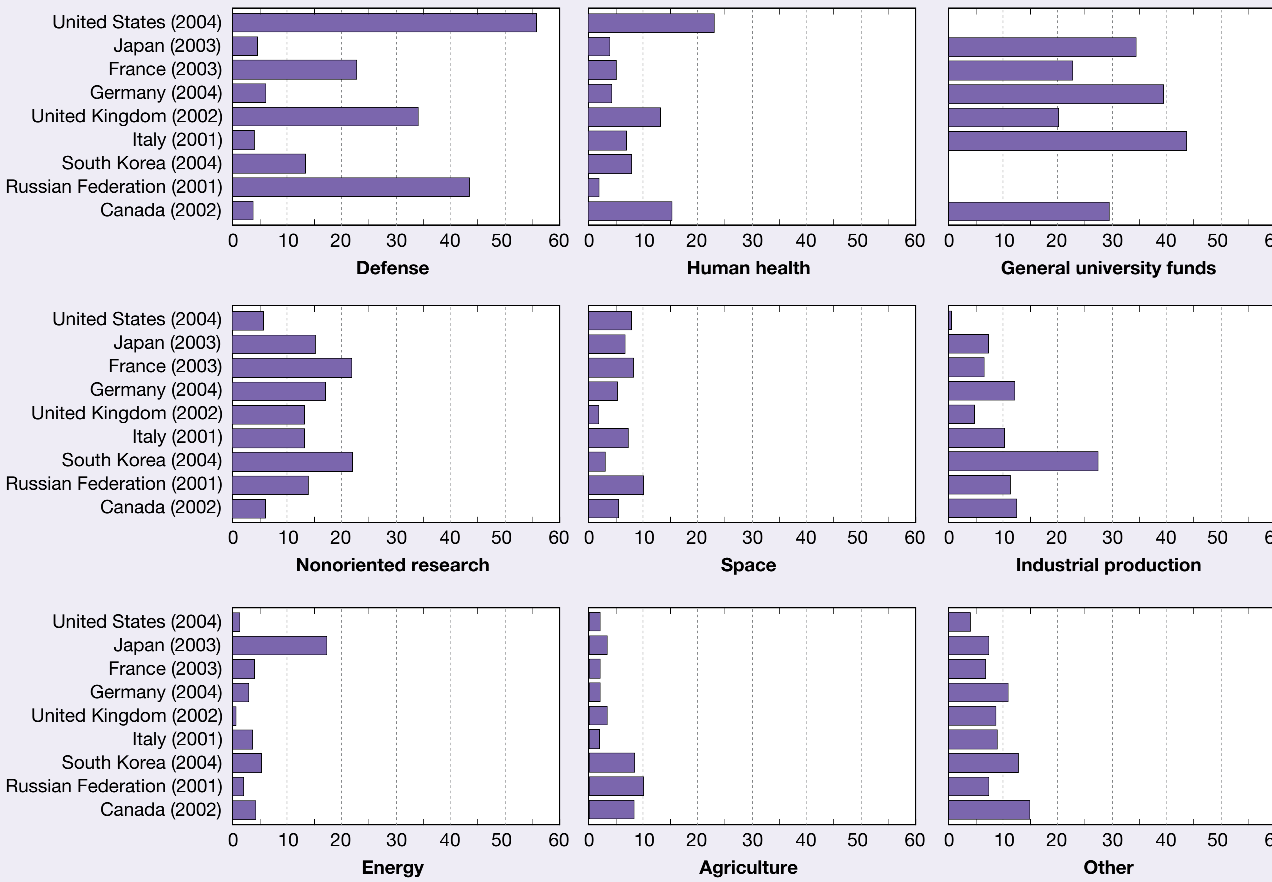
past two decades. In terms of broad socioeconomic objectives, government R&D shares increased most for health and the environment.[73] Growth in health-related R&D financing was particularly strong in the United States, whereas many of the other OECD countries reported relatively higher growth in environmental research programs. In 2001 the U.S. government devoted 24% of its R&D budget to health-related R&D, making such activities second in magnitude only to defense. Conversely, the relative share of government R&D support for economic development programs declined considerably in the OECD, from 38% in 1981 to 22% in 2001. Economic development programs include the promotion of agriculture, fisheries and forestry, industry, infrastructure, and energy, all activities for which privately financed R&D is more likely to be provided without public support.

Differing R&D activities are emphasized in each country's governmental R&D support statistics (figure 4-45). As noted above, defense accounts for a relatively smaller government R&D share in most countries than in the United States. In recent years, the defense share was relatively high in Russia, the United Kingdom, and France at 44%, 34%, and 23%, respectively, but was 6% or less in Germany, Italy, Canada, and Japan. In 2004, South Korea expended 13% of its government R&D budget on defense-related activities.

Japan committed 17% of its governmental R&D support to energy-related activities, reflecting the country's historical concern over its high dependence on foreign sources of energy. Canada, Russia, and South Korea all allocate two to three times as much of their R&D budgets to agriculture than the other countries in figure 4-45. Space R&D is emphasized most in France and Russia (8% and 10%, respectively), whereas industrial production R&D accounted for 10% or more of governmental R&D funding in Canada, Germany, Italy, Russia, and South Korea. Industrial production and technology is the leading socioeconomic objective for R&D in South Korea, accounting for 27% of all government R&D. This funding is primarily oriented toward the development of science-intensive industries and is aimed at increasing economic efficiency and technological development.[74] Industrial technology programs accounted for less than 1% of the U.S. total. This figure, which includes mostly R&D funding by NIST, is understated relative to most other countries as a result of data compilation differences. In part, the low U.S. industrial development share reflects the expectation that firms will finance industrial R&D activities with their own funds; in part, government R&D that may be indirectly useful to industry is often funded with other purposes in mind such as defense and space (and is therefore classified under other socioeconomic objectives).

Figure 4-45
Government R&D support, by socioeconomic objectives for G-8 countries and South Korea: Selected years, 2001–04
Percent



NOTES: Countries listed in descending order by amount of total government R&D. Data are for years in parentheses. R&D classified according to its primary government objective, although may support several complementary goals, e.g., defense R&D with commercial spinoffs classified as supporting defense, not industrial development.

SOURCE: Organisation for Economic Co-operation and Development, special tabulations (2005). See appendix table 4-47.

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Compared with other countries, France and South Korea invested relatively heavily in nonoriented research at 22% of government R&D appropriations. The U.S. government invested 6% of its R&D budget in nonoriented research, largely through the activities of NSF and DOE.

R&D Investments by Multinational Corporations

Multinational corporations (MNCs) have been expanding R&D outside their home countries in recent decades (see sidebar "Foreign Direct Investment in R&D"). R&D investments by MNCs, within their affiliates or with external partners in joint ventures and alliances, support the development of new products, services, and technological capabilities. These investments also serve as channels of knowledge spillovers and technology transfer that can contribute to economic growth and enhance competitiveness. International R&D links are particularly strong between U.S. and European companies, especially in pharmaceutical, computer, and transportation equipment manufacturing. More recently, certain developing or newly industrialized economies are emerging as hosts of U.S.-owned R&D, including China, Israel, and Singapore.

U.S. Affiliates of Foreign Companies

U.S. affiliates of foreign companies have a substantial presence in the U.S. economy. Their value added as percent of total U.S. private industry value added grew from 4.9% in 1997 to 5.7% in 2002 (Zeile 2004). Within U.S. affiliates, the largest industries in terms of value added were wholesale trade (16.8%), which includes large affiliates with substantial secondary operations in manufacturing, chemicals (9.6%), transportation equipment (7.6%), and computer and electronic products (4.9%) in 2002 (Zeile 2004:198). Economic

Foreign Direct Investment in R&D

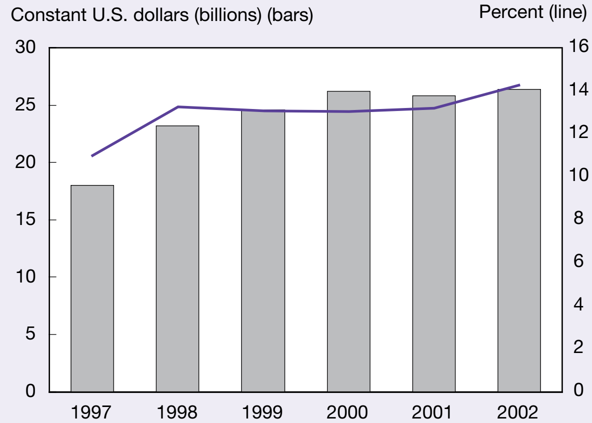
Direct investment refers to the ownership of productive assets outside the home country by multinational corporations (MNCs). More specifically, the U.S. Bureau of Economic Analysis (BEA) defines direct investment as ownership or control of 10% or more of the voting securities of a business in another country. A company located in one country but owned or controlled by a parent company in another country is known as an affiliate. Affiliate data used in this section are for majority-owned affiliates, i.e., those in which the ownership stake of parent companies is more than 50%. Statistics on R&D by affiliates of foreign companies in the United States and by foreign affiliates of U.S. MNCs and their parent companies are part of operations data obtained from BEA's Survey of Foreign Direct Investment in the United States (FDIUS) and BEA's Survey of U.S. Direct Investment Abroad (USDIA), respectively. Operations data exclude depository institutions and are on a fiscal-year basis.

Global R&D supports a range of objectives, from production to technology adaptation to development of new products or services (Kumar 2001; Niosi 1999). The location decision for global R&D sites is driven by (1) market-based and science-based factors, ranging from cost considerations and the pull of large markets to the search for location-specific expertise (von Zedtwitz and Gassmann 2002); (2) the balance between home- and overseas-based advantages in advancing corporate technology goals (Bas and Sierra 2002); and (3) the focus of R&D in terms of research or development. Barriers or challenges include intellectual property protection and coordination and management issues (EIU 2004).

activities by U.S. affiliates of foreign companies, including production, employment, and R&D among others, reflect the combined effect of new investment flows, either as new facilities or through mergers and acquisitions, as well as changes in their existing U.S. operations.[75] According to BEA, new investments flows in the United States by foreign direct investors (measured as investment outlays for businesses established or acquired) increased substantially between 1998 and 2000, before declining consecutively in 2001 and 2002, along with sluggish U.S. economic activity and slower worldwide mergers and acquisitions (Anderson 2004).[76]

R&D expenditures by majority-owned U.S. affiliates of foreign companies (henceforth, U.S. affiliates) grew substantially in the late 1990s, concurrently with large investments inflows, followed by smaller but still significant increases in the early 2000s. In 2002, R&D performed by majority-owned U.S. affiliates reached $27.5 billion, an increase of 2.3% from 2001 (after adjusting for inflation) (appendix table 4-48). By comparison, total U.S. industrial R&D performance (which

Figure 4-46
R&D performed by U.S. affiliates of foreign companies and share of total U.S. industry R&D: 1997–2002



NOTE: Affiliates' data are for majority-owned companies and are preliminary estimates for 2002.

SOURCES: National Science Foundation, Division of Science Resources Statistics, Survey of Industrial Research and Development (annual series); and U.S. Department of Commerce, Bureau of Economic Analysis, Survey of Foreign Direct Investment in the United States (annual series).

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includes all companies located in the United States regardless of ownership status) declined by 5.6%, after adjusting for inflation. U.S. affiliates' R&D expenditures accounted for 14.2% of total U.S. industrial R&D performance in 2002 compared with just above 13% from 1998 to 2001 (figure 4-46). Of the $27.5 billion in R&D performed by U.S. affiliates in 2002, $24.9 billion was performed for affiliates themselves; $2.1 billion for others (including their foreign parents and affiliates of the same company located outside the United States); and $555 million was performed for the U.S. federal government (appendix table 4-50).

Manufacturing accounted for about three-fourths of U.S. affiliates' R&D, including 29% in chemicals, 18% in computer and electronic products, and 12% in transportation equipment (table 4-16; appendix table 4-49). U.S. affiliates owned by European parent companies accounted for three-fourths ($20.7 billion of $27.5 billion) of U.S. affiliates R&D in 2002 (figure 4-47), reflecting their sizable investment shares in the U.S. economy and their focus in R&D-intensive industries. German-owned affiliates classified in transportation equipment performed $2.4 billion of R&D in 2002, which represented 75% of all U.S. affiliates' R&D in this industry and 42% of total R&D performed by German-owned U.S. affiliates (table 4-16). On the other hand, Swiss- and British-owned affiliates were notable within chemicals, which includes pharmaceuticals and medicines, performing a combined 57% of chemicals R&D by U.S. affiliates.

Majority-owned U.S. affiliates of foreign companies employed 128,100 R&D personnel in 2002, up 0.6% from 2001.[77] Over the same period, affiliates' overall employment

Table 4-16
R&D performed by majority-owned affiliates of foreign companies in United States, by selected NAICS industry of affiliate and country/region: 2002
(Millions of current U.S. dollars)

		Manufacturing						Nonmanufacturing	
Country/region	All industries	Total	Chemicals	Machinery	Computer and electronic products	Electrical equipment	Trans-portation equipment	Information	Professional, technical, scientific services
All countries	27,508	20,228	7,997	1872	4,885	396	3,183	723	964
Canada	1,583	1154	33	3	D	D	D	D	41
Europe	20,735	16,151	7,514	1605	2653	333	2,950	482	322
France	2,620	2,026	977	29	537	124	96	209	29
Germany	5,659	5,136	1,395	1110	79	24	2394	D	0
Netherlands	1,773	1,684	451	164	872	2	33	0	33
Switzerland	3,295	2,770	2,506	35	20	D	0	D	D
United Kingdom	5,459	3,797	2,055	63	1112	16	289	113	D
Asia/Pacific	3,263	1,283	386	D	465	19	125	D	600
Japan	D	1,218	383	63	432	19	125	D	599
Latin America/other Western Hemisphere	1,035	848	0	184	D	D	0	—	0
Middle East	D	D	D	0	57	0	0	11	0
Africa	35	D	D	0	0	0	0	D	0

— = ≤ $500,000; D = data withheld to avoid disclosing operations of individual companies
NAICS = North American Industry Classification System

NOTES: Preliminary 2002 estimates for majority-owned (>50%) nonbank affiliates of nonbank U.S. parents by country of ultimate beneficial owner and industry of affiliate. Expenditures included for R&D conducted by foreign affiliates, whether for themselves or others under contract. Expenditures excluded for R&D conducted by others for affiliates under contract.

SOURCE: U.S. Department of Commerce, Bureau of Economic Analysis, Survey of Foreign Direct Investment in the United States (annual series), http://www.bea.gov/bea/di/di1fdiop.htm. See appendix tables 4-48 and 4-49.

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declined by 3.1%. Manufacturing affiliates represented 41% of affiliates' overall employment but over three-fourths of R&D employment in 2002, consistent with their large share in R&D expenditures. For trends in R&D employment in all U.S. affiliates of foreign companies in the 1990s, see NSF/SRS (2004b).

U.S. MNCs and Their Overseas R&D

In 2002, majority-owned foreign affiliates of U.S. MNCs (henceforth, foreign affiliates), performed $21.2 billion in R&D abroad, up 5.6% from 2001, after adjusting for inflation.[78] Except for 2001, R&D expenditures by foreign affiliates increased annually from 1994 to 2002 (table 4-17). After modest increases through 1998, affiliates' R&D expenditures accelerated in 1999, in part due to international mergers and acquisitions.

U.S. MNCs comprise U.S. parent companies plus their foreign affiliates.[79] From 1994 to 2002, more than 85% of the combined global R&D expenditures by U.S. MNCs were performed at home (table 4-17). However, R&D expenditures by foreign affiliates grew at a faster rate (average annual rate of 7.5%) over this period than did R&D expenditures by their U.S. parent companies at home (5.3%). Consequently, the share of foreign affiliates' R&D expenditures within the global MNC increased from 11.5% in 1994 to 13.3% in 2002.[80]

Furthermore, the geographic distribution of these expenditures has evolved to reflect the extent of globalization (figure 4-48). In 1994, major developed economies or regions (Canada, Europe, and Japan) accounted for 90% of overseas R&D expenditures by U.S. MNCs. By 2001, this combined share was down to 80%.[81] The change reflects modest expenditures growth in European locations, compared with larger increases in Asia (outside Japan) and in Israel. Nevertheless, affiliates located in Europe accounted for at least 60% of these R&D expenditures in 2001 and in 2002, led by the United Kingdom and Germany (figure 4-47; appendix table 4-51).

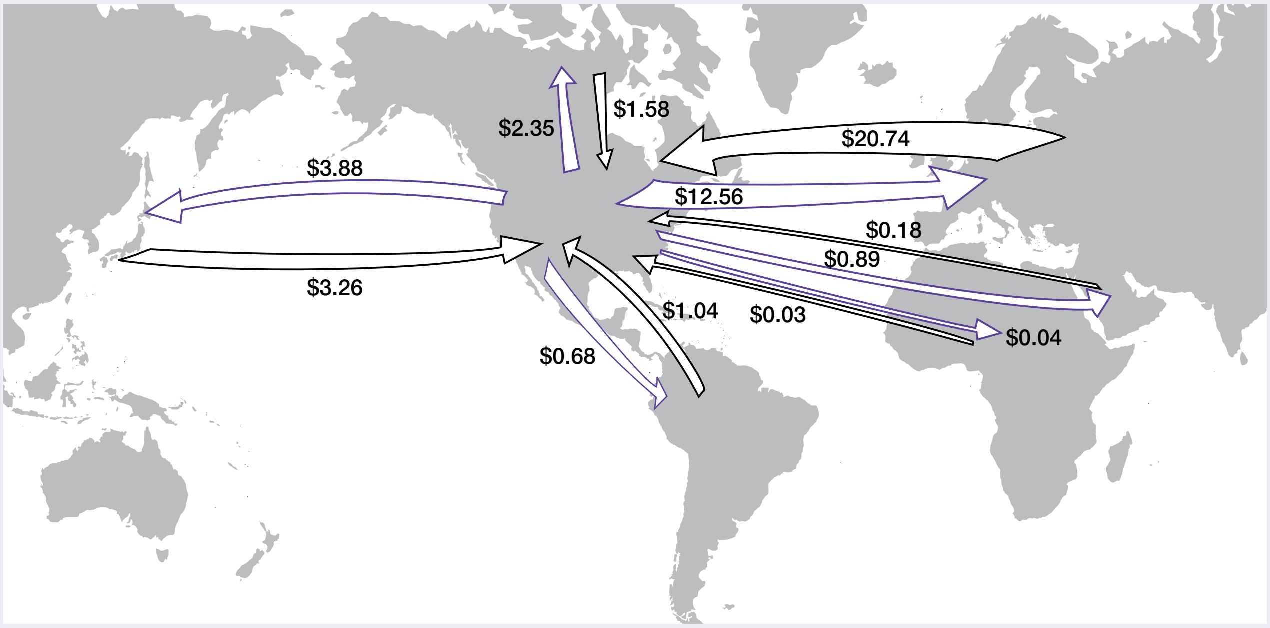
R&D expenditures by foreign affiliates in mainland China and Singapore accelerated in 1999, exceeding half a billion dollars annually since 2000. By 2002, they became, respectively, the second and third largest Asia-Pacific hosts of U.S. R&D after Japan and ahead of Australia, according to available data (appendix table 4-51).[82]

Brazil and Mexico have represented around 80% or more of R&D expenditures by U.S. MNCs in Latin America since 1994. Finally, Israel and South Africa represent virtually all of the R&D expenditures by U.S. MNCs in their respective regions over the same period (appendix table 4-51).

Three manufacturing industries accounted for most foreign affiliate R&D in 2002: transportation equipment (28%), computer and electronic products (25%), and chemicals (including pharmaceuticals) (23%) (table 4-18; appendix table

Figure 4-47
R&D performed by U.S. affiliates of foreign companies in U.S. by investing region and by foreign affiliates of U.S. multinational corporations by host region: 2002 or latest year

(Billions of current dollars)



NOTES: Preliminary estimates for 2002. Regional totals for foreign affiliates of U.S. multinational corporations located in Europe and in Latin America and other Western Hemisphere are sums computed by National Science Foundation based on available country data for those regions. Data for foreign affiliates located in Africa and for U.S. affiliates of foreign companies from Middle East are for 2001.

SOURCES: U.S. Department of Commerce, Bureau of Economic Analysis, Survey of Foreign Direct Investment in the United States; and Survey of U.S. Direct Investment Abroad. See appendix tables 4-48 and 4-51.

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Table 4-17
R&D performed by parent companies of U.S. multinational corporations and their majority-owned foreign affiliates: 1994–2002

	R&D performed (current U.S. $ millions)			Shares of MNC (%)	
Year	U.S. parents	MOFAs	Total MNCs	U.S. parents	MOFAs
1994	91,574	11,877	103,451	88.5	11.5
1995	97,667	12,582	110,249	88.6	11.4
1996	100,551	14,039	114,590	87.7	12.3
1997	106,800	14,593	121,393	88.0	12.0
1998	113,777	14,664	128,441	88.6	11.4
1999	126,291	18,144	144,435	87.4	12.6
2000	135,467	20,457	155,924	86.9	13.1
2001	143,017	19,702	162,719	87.9	12.1
2002	137,968	21,151	159,119	86.7	13.3

MNC = multinational corporation; MOFA = majority-owned foreign affiliate

NOTES: Detail may not add to total because of rounding. MOFAs are affiliates in which combined ownership of all U.S. parents is >50%. See appendix tables 4-51 and 4-53.

SOURCE: U.S. Department of Commerce, Bureau of Economic Analysis, Survey of U.S. Direct Investment Abroad (annual series), http://www.bea.gov/bea/di/di1usdop.htm.

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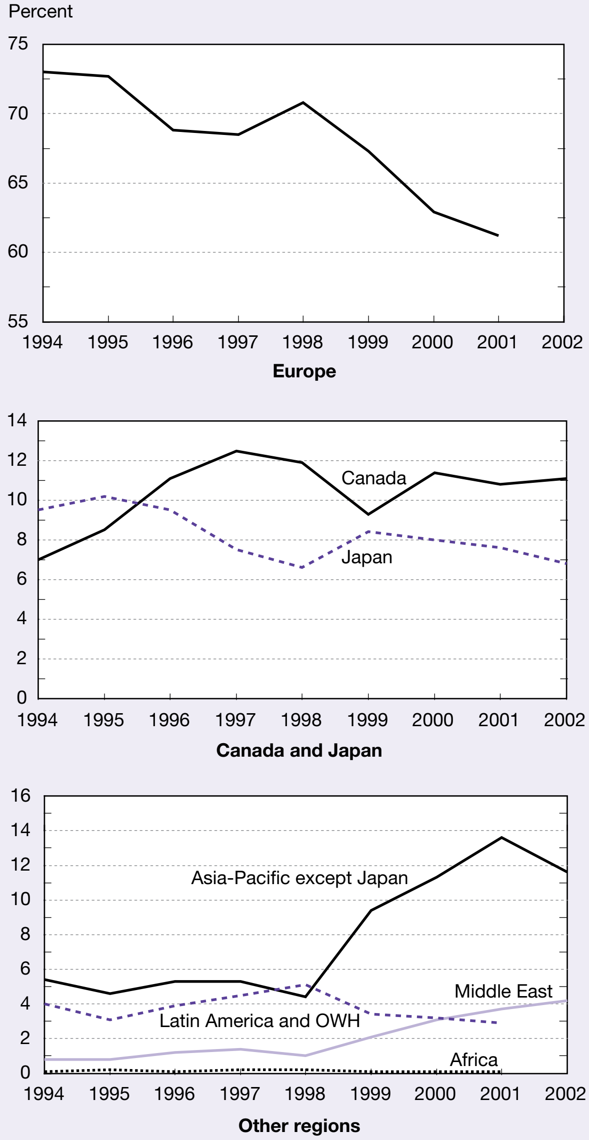
Figure 4-48
Regional shares of R&D performed abroad by foreign affiliates of U.S. MNCs: 1994–2002



MNC = multinational corporation; OWH = other Western Hemisphere

NOTES: Data for majority-owned affiliates. Preliminary estimates for 2002. Preliminary estimates for regional totals for Africa, Europe, and Latin America and other Western Hemisphere are not available.

SOURCE: U.S. Department of Commerce, Bureau of Economic Analysis, Survey of U.S. Direct Investment Abroad (annual series). See appendix table 4-51.

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4-52). The largest nonmanufacturing R&D-performing industry was professional, technical, and scientific services (which include R&D and computer services), with 6% of the total. The industry distribution in European locations is similar to the average across all host countries, whereas half of affiliates' R&D expenditures in Canada and Japan are performed by affiliates classified in transportation equipment and chemicals, respectively. More than half of foreign affiliates' R&D located in the Asia-Pacific region and in Israel was performed by affiliates classified in computer and electronic products.[83]

Comparison of R&D Expenditures by U.S. Affiliates of Foreign Companies and Foreign Affiliates of U.S. MNCs

From 1997 to 2002, R&D expenditures by U.S. affiliates of foreign companies grew faster than did R&D expenditures of foreign affiliates of U.S. MNCs (9.8% average annual growth rate and 7.7%, respectively). The difference between these two indicators of international R&D activity in the United States and activity by U.S. MNCs overseas jumped by $5 billion to $7.7 billion at the start of the movement by foreign MNCs in 1998 toward large U.S. investments. Since then, this difference has remained between $5.7 and $6.7 billion (figure 4-49), or close to 3% of total U.S. industrial R&D. At the regional level, R&D expenditures by European-owned companies in the United States accounted for most of this difference. Within chemical manufacturing (which includes pharmaceuticals and medicines), affiliates of foreign companies in the United States performed $3.2 billion more in R&D expenditures compared with foreign affiliates of U.S. MNCs. Conversely, foreign affiliates of U.S. MNCs classified in transportation equipment performed $2.7 billion more in R&D expenditures compared with transportation equipment affiliates of foreign companies in the United States. For information on an ongoing project investigating the development of integrated statistical information on these U.S. and cross-border R&D investments, see sidebar "Indicators Development on R&D by MNCs."

Table 4-18
R&D performed overseas by majority-owned foreign affiliates of U.S. parent companies, by selected NAICS industry of affiliate and country/region: 2002
(Millions of current U.S. dollars)

		Manufacturing						Nonmanufacturing	
Country/region	All industries	Total	Chemicals	Machinery	Computer and electronic products	Electrical equipment	Trans-portation equipment	Information	Professional, technical, scientific services
All countries	21,151	18,696	4,819	642	5,278	418	5,898	507	1,237
Canada	2,345	2,272	438	25	510	13	1,170	29	16
Europe	D[a]	11,718	3,305	488	2,175	271	4,321	260	D
France	1,480	1,386	693	38	241	20	211	D	32
Germany	3,603	3,376	259	149	683	138	1,855	3	32
Sweden	1,316	1,296	86	32	12	D	D	0	D
Switzerland	405	162	48	16	48	D	D	2	D
United Kingdom	3,735	3,238	1,168	140	636	14	954	38	400
Asia/Pacific	3,881	3,530	890	85	2,024	D	D	D	D
Australia	329	286	68	5	21	—	130	0	28
China	646	609	33	2	D	D	1	D	D
Japan	1,433	1,283	732	50	375	D	25	D	D
South Korea	167	149	10	11	90	2	27	8	6
Singapore	589	578	11	—	550	5	D	1	5
Taiwan	70	D	16	9	25	0	D	D	1
Latin America/other Western Hemisphere	D[a]	633	172	33	71	D	189	D	D
Brazil	306	298	68	28	30	D	D	D	3
Mexico	284	185	49	5	2	1	D	0	D
Middle East	889	520	2	9	498	0	0	56	D
Israel	889	520	2	9	498	0	0	56	D
Africa	D[a]	25	12	2	0	0	D	—	—

— = ≤ $500,000; D = data withheld to avoid disclosing operations of individual companies
NAICS = North American Industry Classification System

[a]Corresponding values for 2001 were $12,060 million (Europe), $562 million (Latin America/other Western Hemisphere), and $29 million (Africa).

NOTES: Preliminary 2002 estimates for majority-owned (>50%) nonbank affiliates of nonbank U.S. parents by country of ultimate beneficial owner and industry of affiliate. Expenditures included for R&D conducted by foreign affiliates, whether for themselves or others under contract. Expenditures excluded for R&D conducted by others for affiliates under contract.

SOURCE: U.S. Department of Commerce, Bureau of Economic Analysis, Survey of U.S. Direct Investment Abroad (annual series), http://www.bea.gov/bea/di/di1usdop.htm. See appendix table 4-51.

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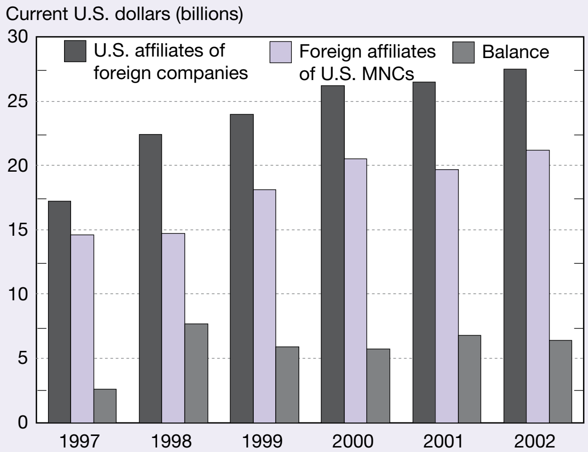
Indicators Development on R&D by MNCs

In recognition of the increasing international dimensions of U.S. R&D, the National Science Foundation (NSF) Division of Science Resources Statistics proposed and funded a 3-year exploratory project aimed at the integration of statistical information from the Bureau of Economic Analysis' (BEA's) international investment surveys with the NSF Survey of Industrial Research and Development, which is conducted by the U.S. Census Bureau.

The study demonstrated the feasibility of linking companies covered in the BEA MNC surveys with those covered by the NSF Survey of Industrial R&D. The study also generated statistical benefits by expanding the sampling frame of participant surveys. Further, the project confirmed that, for the most part, the data reported to the U.S. Census Bureau and BEA are comparable, and it also documented definitional and methodological differences that warrant further statistical and analytical investigation. If future links are undertaken, integrated data may support a richer analysis of R&D patterns, including MNCs' R&D spending by character of work and by state location.

Figure 4-49
R&D by U.S. affiliates of foreign companies and foreign affiliates of U.S. MNCs: 1997–2002



MNC = multinational corporation

NOTES: Data for majority-owned affiliates. Balance is R&D by U.S. affiliates of foreign companies minus R&D of foreign affiliates of U.S. MNCs.

SOURCES: U.S. Department of Commerce, Bureau of Economic Analysis, Survey of Foreign Direct Investment in the United States (annual series); and Survey of U.S. Direct Investment Abroad (annual series). See appendix tables 4-48 and 4-51.

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Conclusion

The rapid growth in R&D investment in the United States from 1994 to 2000 fell victim to stock market decline and slower economic pace in the first years of the 21st century. As a result, U.S. R&D experienced its first decline in almost 50 years in 2002. The decline lasted only 1 year as R&D growth accelerated in 2003 and 2004.

Reaction to acts of terrorism and military mobilizations have reversed a declining trend in the U.S. government's share of defense-related R&D. Other countries throughout the world have maintained their focus on nondefense R&D and have attempted to take proactive steps toward intensifying and focusing their national R&D activity. These steps range from increasing general government spending to fostering high-technology industrial clusters.

The locus of R&D activities is also shifting as a reflection of broad technological changes and new scientific research opportunities. Industrial R&D is increasingly undertaken in service (versus manufacturing) industries, and much of the industrial R&D growth has occurred in biotechnology and information technology. Moreover, federal research funds have shifted markedly toward the life sciences over the past decade.

Cross-country R&D investments through MNCs continue to be strong between U.S. and European companies. At the same time, certain developing or newly industrialized economies are emerging as significant hosts of U.S.-owned R&D, including China, Israel, and Singapore. U.S. MNCs continued expanding R&D activity overseas, but foreign MNCs in the United States have increased their R&D expenditures even more.

The significance of these trends for the R&D enterprise, national competitiveness, and public policy is difficult to assess. For example, MNC trends reflect the combined effect of different investment strategies including mergers and acquisitions, the establishment of new facilities, and changes in existing laboratories, service centers, and manufacturing plants. Furthermore, no information exists below aggregate R&D expenditures for MNC data.

In part to address these challenges, NSF, in partnership with the U.S. Census Bureau, which conducts the NSF Survey of Industrial Research and Development, and BEA, which conducts the international investment surveys, completed a study aimed at developing a methodology to integrate information from the different surveys. The study demonstrated the feasibility of linking this information. If future links are undertaken, integrated data may yield new indicators such as MNCs' R&D spending by character of work and by state location. A separate statistical project between NSF and BEA, which also publishes GDP and other national economic accounts data, is directed at integrating R&D expenditure data into national accounts methodology by means of a satellite account for R&D. A satellite account framework recognizes the investment characteristics of R&D, facilitating the measurement and assessment of its role in long-term productivity and economic growth. Additional investigations on the role of partnerships, joint ventures, and transactions in R&D services are warranted in an increasingly diffused web of R&D and innovation players across the globe.

Notes

1. Growth in the R&D/GDP ratio does not necessarily imply increased R&D expenditures. For example, the rise in R&D/GDP from 1978 to 1985 was due as much to a slowdown in GDP growth as it was to increased spending on R&D activities.

2. Expenditures R&D performance are used as a proxy for actual R&D performance. In this chapter, the phrases *R&D performance* and *expenditures for R&D performance* are interchangeable.

3. See appendix table 4-1 for the GDP implicit price deflators used to adjust expenditures to account for inflation.

4. For most manufacturing industries, the U.S. Small Business Administration defines *small firm* as one with 500 or fewer employees. The share of company-financed R&D performed by these firms grew from 10% in 1990 to a peak of 20% in 1999.

5. FFRDCs are R&D-performing organizations that are exclusively or substantially financed by the federal government either to meet a particular R&D objective or, in some instances, to provide major facilities at universities for research and associated training purposes. Each FFRDC is administered either by an industrial firm, a university, or a

nonprofit institution. In some of the statistics provided in this chapter, FFRDCs are included as part of the sector that administers them. In particular, statistics on the industrial sector often include industry-administered FFRDCs because some of the statistics from the NSF Survey of Industrial Research and Development before 2001 cannot be separated from the FFRDC component.

6. Recent methodological improvements in the estimation of total academic R&D have resulted in a break in the time series. Data for years before 1998 are slightly overstated compared with the data for later years. See NSF/SRS (forthcoming) for details on the changes to methodology.

7. These findings are based on performer-reported R&D levels. In recent years, increasing differences have been detected in data on federally financed R&D as reported by federal funding agencies and by performers of the work (most notably, industrial firms and universities). This divergence in R&D totals is discussed later in this chapter. (See sidebar, "Tracking R&D: Gap Between Performer- and Source-Reported Expenditures.")

8. The latest data available on the state distribution of R&D performance are for 2003. In 2003, $277.5 billion of the $291.9 billion total U.S. R&D could be attributed to expenditures within individual states, with the remainder falling under an undistributed "other/unknown" category. Approximately two-thirds of the R&D that could not be associated with a particular state was R&D performed by the nonprofit sector.

9. Rankings do not take into account the margin of error of estimates from sample surveys. NSF, Division of Science Resources Statistics, Survey of Industrial Research and Development, 2005. Available at http://www.nsf.gov/sbe/srs/indus/start.htm.

10. GSP is often considered the state counterpart of the nation's GDP. GSP is estimated by summing the *value added* of each industry in a state. Value added for an industry is equivalent to its gross output (sales or receipts and other operating income, commodity taxes, and inventory change) minus its intermediate inputs (consumption of goods and services purchased from other U.S. industries or imported). U.S. Bureau of Economic Analysis, *Gross State Product* (Washington, DC, 2003). (See http://www.bea.gov/bea/regional/docs/Regional_GSP.pdf)

11. Federal intramural R&D includes costs associated with the administration of intramural and extramural programs by federal personnel as well as actual intramural R&D performance. This explains the large amount of federal intramural R&D reported within the District of Columbia.

12. http://www.thirdfrontier.com/overview.asp

13. For most manufacturing industries, the U.S. Small Business Association has established a size standard of 500 employees. The NSF Survey of Research and Development in Industry does not sample companies with fewer than five employees because of concerns over respondent burden.

14. A similar measure of R&D intensity is the ratio of R&D to *value added* (sales minus the cost of materials). Value added is often used in studies of productivity because it allows analysts to focus on the economic output attributable to the specific industrial sector in question by subtracting materials produced in other sectors. For a discussion of the connection between R&D intensity and technological progress, see, for example, R. Nelson, Modeling the connections in the cross section between technical progress and R&D intensity, *RAND Journal of Economics* 19(3) (Autumn 1988):478–85.

15. Industry-level estimates are complicated by the fact that each company's R&D is reported in only one industry. (See sidebar, "Industry Classification Complicates Analysis.")

16. Details on how companies are assigned industry codes in the NSF Survey of Industrial Research and Development can be found on the NSF website (http://www.nsf.gov/statistics/nsf02312/sectb.htm#frame). NSF, Division of Science Resources Statistics, Survey of Industrial Research and Development, 2003. Available at http://www.nsf.gov/sbe/srs/indus/start.htm.

17. Lower bound analyst estimates will be given in cases where disclosure of company-reported data or classification issues prevents the publication of total estimates from survey data.

18. Methodological differences between the PhRMA Annual Membership Survey and the NSF Survey of Industrial Research and Development make it difficult to directly compare estimates from the two surveys. For example, the PhRMA survey definition of R&D includes Phase IV clinical trials whereas the NSF survey definition does not.

19. Although disclosure of federal R&D funding prohibited the precise tabulation of total R&D performance for this industry, total R&D was at least $27.4 billion in 2003.

20. The introduction of a more refined industry classification scheme in 1999 allowed more detailed reporting in nonmanufacturing industries. For the cited 2003 statistic, the R&D of companies in software, other information, and computer systems design and related services industries were combined. These three industries provided the closest approximation to the broader category cited for earlier years without exceeding the coverage of the broader category.

21. NAICS-based R&D estimates are only available back to 1997. Estimates for 1997 and 1998 were bridged from a different industry classification scheme. Total R&D for this sector has grown from $9.2 billion in 1997 to $17.6 billion in 2003.

22. Company annual reports accessed 25 March 2005 at http://www.sec.gov/edgar.shtml. Because R&D expenses reported on financial documents differ from the data reported on the NSF Survey of Industrial Research and Development, direct comparisons of these sources are not possible. See C. Shepherd and S. Payson, *U.S. R&D Corporate R&D* (Washington, DC: National Science Foundation, 2001) for an explanation of the differences between the two.

23. FASB, SFAS 123 (Dec. 2004) (http://www.fasb.org/pdf/fas123r.pdf).

24. Microsoft Corporation, 2004 Microsoft Annual Report, Note 13.

25. DOD reports development obligations in two categories: *advanced technology development,* which is similar in nature to development funded by most other agencies, and *major systems development,* which includes demonstration and validation, engineering and manufacturing development, management and support, and operational systems development for major weapon systems.

26. In 2005, 73% of all federal research funding was allocated through competitive merit review processes. Fifteen percent was merit reviewed, but competition was limited to a select pool of applicants such as federal laboratories or FFRDCs. Seven percent was awarded to performers for inherently unique research without competitive selection. The remaining 4% was allocated to specific performers at the request of Congress (U.S. OMB 2005).

27. Since 2003 one new FFRDC has been established: the Homeland Security Institute in Arlington, Virginia.

28. Most of the $2.5 trillion federal budget is reserved for mandatory items such as Social Security, Medicare, pension payments, and payments on the national debt. See appendix table 4-28 for historical data on federal outlays and R&D.

29. For tax purposes, R&D expenses are restricted to the somewhat narrower concept of research and experimental (R&E) expenditures. Such expenditures are limited to experimental or laboratory costs aimed at the development or improvement of a product in connection with the taxpayer's business. Furthermore, the R&E tax-credit applies to a subset of R&E expenses based on additional statutory requirements. See Section 41 of the U.S. Internal Revenue Code (U.S. Code of Federal Regulations, Title 26). For further details on the R&E tax credit and a separate tax R&E incentive, the R&E tax expensing allowance, see NSF/SRS (2005) and references therein.

30. Both indirect incentives and direct federal funding are federal expenses. Tax incentives generate tax expenditures: government revenue losses due to tax exclusions or deductions. For estimates of tax expenditures arising from the R&E tax credit, see OMB (2005).

31. Public Law No. 108-311, Title III, Section 301. The R&E tax credit was not in place for activities conducted from July 1995 to June 1996.

32. The effective rate is considered to be lower than this statutory rate due in part to limitations involving other business credits and allowances.

33. Exclude data from IRS tax forms 1120S (S corporations), 1120-REIT (Real Estate Investment Trusts), and 1120-RIC (Regulated Investment Companies). The latest available data for R&E claims at the time of this writing were for 2001.

34. In this section, the term contract R&D is used generically to denote a transaction with external parties involving R&D payments or income, regardless of the actual legal form of the transaction. Data in this section cover R&D contract expenses paid by U.S. R&D performers (using company and other nonfederal R&D funds) to other domestic companies. Data on contract R&D expenses by domestic companies that do not perform internal R&D or that contract out R&D to companies located overseas are not available.

35. Three-fourths of contracted-out R&D paid by pharmaceutical companies was performed by other private companies. The balance was performed by universities and colleges, other nonprofit organizations, and other organizations. Further analysis for other industries is precluded by large amounts of undistributed contract R&D expenses.

36. For conceptual, policy, and measurement issues regarding indicators of technology alliances, J.E. Jankowski, A.N. Link, and N.S. Vonortas, *Strategic Research Partnerships: Proceedings From an NSF Workshop*, NSF 01-336 (Arlington, VA: National Science Foundation, 2001); and B. Bozeman and J.S. Dietz. 2001. Strategic research partnerships: Constructing policy-relevant indicators, *Journal of Technology Transfer* 26:385–93.

37. Further, industrial technology alliances have been found to be countercyclical, whereby companies turn to partners to leverage scarce or more costly investment opportunities in the face of a slower economy (Brod and Link 2001; Link, Paton, and Siegel. 2002; Vonortas and Hagedoorn 2003).

38. As amended by the National Cooperative Research and Production Act (NCRPA) of 1993 (Public Law 103-42). See U.S. Code Title 15, Chapter 69.

39. The amendment was instituted by the Cooperative Research and Technology Enhancement (CREATE) Act of 2004 (Public Law 108-453) and applies to patents resulting from joint research as long as the claimed invention is within the scope of a written contract, grant, or cooperative agreement and made by or on behalf of the parties to the agreement.

40. To gain protection from antitrust litigation, the statute requires firms engaging in research joint ventures in the United States to register these agreements with the Department of Justice. Trends in the CORE database are illustrative only since the registry is not intended to be a comprehensive count of cooperative activity by U.S.-based firms. No data on alliance duration or termination date are available. This database is compiled by A.N. Link, University of North Carolina-Greensboro.

41. CATI-MERIT is a literature-based database that draws on sources such as newspapers, journal articles, books, and specialized journals that report on business events. It includes business alliances with an R&D or technology component such as joint research or development agreements, R&D contracts, and equity joint ventures. Agreements involving small firms and certain technology fields are likely to be underrepresented. Another limitation is that the database draws primarily from English-language materials. No data on alliance duration or termination date are available. This database is maintained by J. Hagedoorn, MERIT, the Netherlands.

42. Furthermore, the decision to enter into an R&D agreement is separate from the decision to register. Using CORE data from 1985–98, Link et al. (2002) found that registrations

were inversely related to the U.S. business cycle and global market shares, used as proxies for conditions that may impact the perceived antitrust climate and the strategic decision to register.

43. See Hagedoorn (2002) for summary of CATI alliances since 1960 and Hagedoorn and van Kranenburg (2003) for a detailed statistical characterization of the data. For analytical purposes, data referring to alliances established in more recent decades are considered more reliable given the increased coverage of R&D agreements in the public sources of the database (see Vonortas and Hagedoorn 2003).

44. Some alliances may be classified in more than one technology. The vast majority of the alliances have been formed as contractual or nonequity alliances since the late 1990s (Appendix table 4-37). See Hagedoorn (2002) for the significance of the shift toward nonequity agreements.

45. Federal laboratories are facilities owned, leased, or otherwise used by a federal agency [15 USC 3710a(d)(2)]. They include, for example, intramural laboratories (e.g., the laboratories owned by NIH's National Cancer Institute) and government-owned contractor-operated laboratories such as some of DOE's FFRDCs. For general information on FFRDCs see footnote 5 and appendix table 4-25.

46. Other types of collaboration include patent licensing, technical assistance, materials and other technical standards development, and use of instrumentation or other equipment.

47. Other data of interest include CRADA-specific agency and industry funding, nature of joint activities, R&D outputs, and industrial impact. For empirical results on some of these indicators from one-time surveys or selected laboratories see Adams, Chiang, and Jensen (2003) and Bozeman and Wittmer (2001).

48. Data for FY 1999 and beyond may not be comparable with prior years because of methodological changes in data collection and processing.

49. Data are for active traditional CRADAS: those legally in force under the authority of 15 U.S. Code Sec. 3710a at any time during the fiscal year. NASA collaborative R&D agreements under the National Aeronautics and Space Act of 1958 are not included. "Traditional" CRADAS are those involving collaborative R&D, in contrast with "nontraditional" CRADAs or those established for special purposes such as material transfer or technical assistance.

50. Note that the latter indicators are not limited to CRADA activity.

51. For more on patents as S&T indicators see chapter 6.

52. At the same time, basic research is also an important component of industry collaborations with federal labs. See J. Rogers and B. Bozeman. 1997. Basic research and the success of federal Lab-industry partnerships, *Journal of Technology Transfer* 22(3):37–48.

53. The 2000 reauthorization bill (Public Law 106-554) also requested that the National Research Council conduct a 3-year SBIR study at five federal agencies with SBIR budgets exceeding $50 million (DOD, HHS, NASA, DOE, and NSF). The study is currently in progress. See NRC (2004) and http://www7.nationalacademies.org/sbir/index.html.

54. Title I of the Small Business Research and Development Enhancement Act, Public Law 102-564.

55. STTR was created by Small Business Technology Transfer Act of 1992 (Title II of the Small Business Research and Development Enhancement Act, Public Law 102-564). It was last reauthorized by the Small Business Technology Transfer Program Reauthorization Act of 2001 (Public Law 107-50) through FY 2009.

56. Public Law 100-418; 15 U.S. Code Section 278n.

57. OECD maintains R&D expenditure data that can be categorized into three periods: (1) 1981 to the present (data are properly annotated and of good quality); (2) 1973 to 1980 (data are probably of reasonable quality, and some metadata are available); and (3) 1963 to 1972 (data are questionable for most OECD countries [with notable exceptions of the United States and Japan], many of which launched their first serious R&D surveys in the mid-1960s). The analyses in this chapter are limited to data for 1981 and subsequent years. The 30 current members of the OECD are Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom, and United States.

58. The global R&D figure is estimated based on data for 80 countries compiled from three sources. Estimates for 31 countries were taken from OECD data, estimates for 18 additional countries were taken from RICYT data, and estimates for the remaining 25 countries were taken from UNESCO reports.

59. Because U.S. universities generally do not maintain data on departmental research, U.S. totals are understated relative to the R&D effort reported for other countries. The national totals for Europe, Canada, and Japan include the research component of GUF block grants provided by all levels of government to the academic sector. These funds can support departmental R&D programs that are not separately budgeted. The U.S. federal government does not provide research support through a GUF equivalent, preferring instead to support specific, separately budgeted R&D projects. However, a fair amount of state government funding probably does support departmental research at public universities in the United States. See sidebar, "Government Funding Mechanisms for Academic Research."

60. The United Kingdom similarly experienced 3 years of declining real R&D expenditures, but its slump took place in 1995, 1996, and 1997. The falling R&D totals in Germany were partly a result of specific and intentional policies to eliminate redundant and inefficient R&D activities and to integrate the R&D efforts of the former East Germany and West Germany into a united German system.

61. Growth in the R&D/GDP ratio does not necessarily imply increased R&D expenditures. For example, the rise in R&D/GDP from 1978 to 1985 was due as much to a slowdown

in GDP growth as it was to increased spending on R&D activities.

62. A significant contributor to GDP growth in 2003 and 2004 was increased private domestic investment in information processing equipment and software. Because increased demand for high-technology goods and services is an incentive for increased R&D expenditures, this component of GDP is a useful indicator of private R&D expenditures by information technology businesses.

63. Nonfederal sources of R&D tracked by NSF include industrial firms, universities and colleges, nonprofit institutions, and state and local governments.

64. In Japan, real GDP declined in both 1998 and 2002.

65. See OECD (1999) for further discussion of these and other broad R&D indicators.

66. In accordance with international standards, the following sectors are recognized sources of funding: all levels of government combined, business enterprises, higher education, private nonprofit organizations, and funds from abroad. Italy's distribution of R&D by source of funds was not available for 2000. In earlier years, government sources accounted for more than half of Italy's R&D, industry accounted for more than 40%, and foreign sources funded the remainder.

67. Among all OECD countries, in 2002 the government sector accounted for the highest funding share in Poland (61%) and the lowest share in Japan (18%).

68. Some of the R&D reported in the trade industry for the United States was redistributed for this analysis.

69. Since the mid-1980s, European Community (EC) funding of R&D has become increasingly concentrated in its multinational Framework Programmes for Research and Technological Development (RTD), which were intended to strengthen the scientific and technological bases of community industry and to encourage it to become more internationally competitive. EC funds distributed to member countries' firms and universities have grown considerably. The EC budget for RTD activities has grown steadily from 3.7 billion European Currency Units (ECU) in the First Framework Programme (1984–87) to 17.5 billion ECU for the Sixth Framework Programme (2003–06). The institutional recipients of these funds tend to report the source as "foreign" or "funds from abroad." Eurostat. 2001. *Statistics on Science and Technology in Europe: Data 1985–99*. Luxembourg: European Communities.

70. OECD data for the U.S. academic sector includes the R&D of university-administered FFRDCs. These FFRDCs performed an estimated $7.3 billion of R&D in 2003.

71. In international S&E field compilations, the natural sciences comprise math and computer sciences, physical sciences, environmental sciences, and all life sciences other than medical and agricultural sciences.

72. Data on the socioeconomic objectives of R&D funding are generally derived from national budgets. Because budgets each have their own distinct methodology and terminology, these R&D funding data may not be as comparable as other types of international R&D data.

73. Health and environment programs include human health, social structures and relationships, control and care of the environment, and exploration and exploitation of the Earth.

74. Historically, Russia has also devoted a large share of government R&D to industrial development. Fully 27% of the government's 1998 R&D budget appropriations for economic programs were used to assist in the conversion of the country's defense industry to civil applications (American Association for the Advancement of Science and Centre for Science Research and Statistics, 2001).

75. For the purposes of BEA FDI surveys, the United Sates includes the 50 states, Washington, DC, Puerto Rico, and all U.S. territories and possessions.

76. New investments more than doubled from 1997 to 1998 to $215 billion, reaching a peak at $336 billion in 2000. In 2001, new investments decreased by more than one-half and have been in the $50–$60 billion range in 2002 and 2003, closer to the levels in the late 1980s and mid-1990s (Anderson 2004).

77. R&D employment data from BEA measure the number of scientist and engineers devoting the majority of their time to R&D.

78. BEA data on overseas R&D and other foreign operations of U.S. MNCs are converted to U.S. dollars using market exchange rates according to *Statement of Financial Accounting Standards No. 52 - Foreign Currency Translation* (U.S. Financial Accounting Standards Board). Constant or inflation-adjusted dollar expenditures are not available. See appendix tables 4-55 and 4-56 for selected data from the NSF Survey of Industrial Research and Development on overseas R&D expenditures by companies with R&D activities in the 50 U.S. states and Washington, DC.

79. BEA defines a parent company of a U.S. multinational corporation (MNC) as an entity (individual, branch, partnership, or corporation), resident in the United States, that owns or controls at least 10% of the voting securities, or equivalent, of a foreign business enterprise. See appendix tables 4-53 and 4-54.

80. R&D employment data for foreign affiliates from BEA are available only in 5-year intervals. According to the latest available data as of early 2005, U.S. MNCs employed a global R&D workforce of 770,300, or close to 3% of their employees in 1999 (NSF/SRS 2004b). U.S. parent companies employed 84% (646,800) of their R&D workers domestically; the remaining 16% (123,500) worked abroad for their foreign affiliates. For analysis of trends in overall overseas employment by affiliates of U.S. MNCs, see Mataloni (2004).

81. Preliminary regional totals for Africa, Europe, and Latin American and Western Hemisphere are not available for 2002.

82. Since the late 1990s, majority-owned affiliates appear to be the preferred investment mode for U.S. MNCs in mainland China, at the expense of alliances or joint ventures (NSF/SRS 2004a).

83. For further analysis, see Moris (2005).

Glossary

Affiliate: A company or business enterprise located in one country but owned or controlled (10% or more of voting securities or equivalent) by a parent company in another country; may be either incorporated or unincorporated.

Applied research: Research aimed at gaining the knowledge or understanding to meet a specific, recognized need; in industry, applied research includes investigations to discover new scientific knowledge that has specific commercial objectives with respect to products, processes, or services.

Basic research: Research aimed at gaining more comprehensive knowledge or understanding of the subject under study without specific applications in mind.

Development: 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.

Federally funded research and development center: R&D-performing organizations exclusively or substantially financed by the federal government either to meet a particular R&D objectives or, in some instances, to provide major facilities at universities for research and associated training purposes; each FFRDC is administered either by an industrial firm, a university, or a nonprofit institution.

Foreign affiliate: Company located overseas but owned by a U.S. parent.

Foreign direct investment: Ownership or control of 10% or more of the voting securities (or equivalent) of a business located outside the home country.

General university fund (GUF): block grants provided by all levels of government in Europe, Canada, and Japan to the academic sector that can be used to support departmental R&D programs that are not separately budgeted; the U.S. federal government does not provide research support through a GUF equivalent.

Gross domestic product: Market value of goods and services produced within a country.

Intellectual property: Intangible property that is the result of creativity; the most common forms of intellectual property include patents, copyrights, trademarks, and trade secrets.

Majority-owned affiliate: Company owned or controlled by more than 50% of the voting securities (or equivalent) by its parent company.

Multinational corporation: A parent company and its foreign affiliates.

National income and product accounts: Economic accounts that display the value and composition of national output and the distribution of incomes generated in its production.

Parent company of a multinational corporation: Company that owns or controls at least 10% of the voting securities (or equivalent) of a foreign affiliate.

Public-private partnership: Type of industrial technology linkage involving at least one public or nonprofit organization such as a university, research institute, or government laboratory; such a partnership may engage in technology codevelopment or cooperative R&D, technology transfer, technology assistance, joint or grant funding, or public procurement and may take the form of a cooperative agreement, grant or procurement programs, professional or student internship or exchange, technology-based business incubator, or research and science parks.

R&D: According to the Organisation for Economic Co-operation and Development, creative work "undertaken on a systematic basis to increase the stock of knowledge—including knowledge of man, culture, and society—and the use of this stock of knowledge to devise new applications."

R&D employees: Scientists and engineers who perform R&D functions.

R&D plant expenditures: Acquisition of, construction of, major repairs to, or alterations in structures, works, equipment, facilities, or land for use in R&D activities.

Research and experimental expenditures: Experimental or laboratory costs aimed at the development or improvement of a product (defined to include any pilot model, process, formula, or technique) in connection with a taxpayer's business.

Technology alliance: Type of industrial technology linkage aimed at codevelopment of new products or capabilities through R&D collaboration.

Technology transfer: Exchange or sharing of knowledge, skills, processes, or technologies across different organizations.

U.S. affiliate: Company located in the United States but owned by a foreign parent.

Value-added: Sales minus the cost of materials.

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