Chapter 5
Academic Research and Development

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Highlights

Financial Resources for Academic R&D

- ♦ **In 2002, U.S. academic institutions spent $33 billion (in constant dollars) on research and development.** The Federal Government provided $19.0 billion, academic institutions $6.7 billion, state and local governments $2.2 billion, industry $2.1 billion, and other sources $2.4 billion.
- ♦ **Over the past 3 decades (1972 to 2002), average annual growth in R&D has been stronger for the academic sector than for any other R&D-performing sector except the nonprofit sector.** During this period, academic R&D rose from 0.23 to 0.35 percent of the gross domestic product.
- ♦ **The academic sector performs more than half of the basic research performed in the United States.** Academic R&D activities have been highly concentrated at the basic research end of the R&D spectrum since the late 1950s. In 2002, an estimated 74 percent of academic R&D expenditures went for basic research, 22 percent for applied research, and 4 percent for development.
- ♦ **The Federal Government continues to provide the majority of funds for academic R&D, although its share has been declining steadily over the past 3 decades.** The Federal Government provided 59 percent of the funding for R&D performed in academic institutions in 2001, down from 68 percent in 1972.
- ♦ **After the Federal Government, academic institutions performing R&D provided the second largest share of academic R&D support.** Except for a brief downturn in the first half of the 1990s, the institutional share of academic R&D support has been increasing steadily during the past 3 decades, nearly doubling to reach 20 percent in 2001.
- ♦ **Industrial R&D support to academic institutions has grown more rapidly (albeit from a small base) than support from all other sources during the past 3 decades.** Industry's share was 6.8 percent in 2001, compared with 2.8 percent in 1972. However, industrial support still accounts for one of the smallest shares of academic R&D funding.
- ♦ **The concentration of academic R&D funds among the top research universities diminished between the mid-1980s and mid-1990s but has remained relatively steady since then.** The share of those institutions in the group below the top 100 increased from 17 to 20 percent of all academic R&D funds during this period, balanced by a decline in the top 20 institutions' share.
- ♦ **Between 1975 and 2001, there was a relative shift in the share of academic R&D funds received by different S&E fields.** Shares increased for engineering, the life sciences, and the computer sciences and declined for the social sciences; the earth, atmospheric, and ocean sciences; the physical sciences; and psychology.
- ♦ **The distribution of Federal and non-Federal funding of academic R&D varies by field.** In 2001, the Federal Government supported about three-fourths of academic R&D expenditures in both physics and atmospheric sciences but one-third or less of the R&D in economics, political science, and the agricultural sciences.
- ♦ **Three agencies were responsible for about 86 percent of Federal obligations for academic R&D: the National Institutes of Health (66 percent), the National Science Foundation (12 percent), and the Department of Defense (8 percent).** Federal agencies emphasize different science and engineering fields in their funding of academic research, with some, such as NIH, concentrating their funding in one field and others, such as NSF, having more diversified funding patterns.
- ♦ **Total space for academic S&E research increased by more than 38 percent between 1988 and 2001, up from about 112 million to 155 million net assignable square feet.** During this period, very little changed in the distribution of research space across S&E fields: 90 percent of the space continued to be distributed among six fields—the biological sciences, the medical sciences, the agricultural sciences, engineering, the physical sciences, and the earth, atmospheric, and ocean sciences.
- ♦ **R&D equipment intensity—the share of all annual R&D expenditures spent on research equipment—has declined dramatically during the past 15 years.** After reaching a high of 7 percent in 1986, R&D equipment intensity declined by about one-third, to 4.6 percent in 2001.

Doctoral Scientists and Engineers in Academia

- ♦ **Long-term growth of doctoral scientists and engineers employed at U.S. universities and colleges was slower than that in business, government, and other segments of the economy.** As a result, the academic employment share dropped from 53 to 44 percent during the 1975–2001 period.
- ♦ **Full-time faculty positions increased more slowly than postdoc and other full- and part-time positions, especially at research universities.** Those entering research universities in 2001 with recently earned doctorates were more likely to receive postdoc (53 percent) than faculty positions (30 percent). Of those with a doctorate earned 4–7 years earlier who were employed at research universities, less than 40 percent were in tenure track positions in 2001, well below the experience of previous decades.

- **An academic researcher pool outside the regular faculty ranks has grown over the years.** As the faculty share of the academic workforce has declined, more research activity is being carried out by postdocs and others in full-time nonfaculty positions. This change toward nonfaculty research effort was pronounced in the 1990s. A long-term upward trend shows the number of those whose primary activity is research increasing relative to total employment.
- **Among recent doctorate holders employed in academia, the percentage of white males has fallen dramatically, from 73 percent in 1975 to 41 percent in 2001.** This decline has been offset by increases in the hiring of women, Asian/Pacific Islanders, and underrepresented minorities.
- **More than 20 percent of scientists and engineers with U.S. doctoral degrees employed at U.S. universities and colleges in 2001 were foreign born.** Computer sciences and engineering had the highest percentages (39 and 35 percent, respectively), followed by mathematics (28 percent) and the physical, life, and social sciences (from 23 to 19 percent). These estimates are conservative, in that they do not include those with doctorates from foreign institutions.
- **The academic doctoral labor force has been aging during the past quarter of a century.** Both the mean and median age have increased almost monotonically between 1975 and 2001. In 2001, a growing, albeit small, fraction of employment was made up of individuals age 65 or older (4.0 percent) and 70 years or older (1.1 percent). These percentages were slightly higher at research universities than at other academic institutions.
- **Graduate students play a key role in U.S. academic S&E research, and research assistantships were the primary means of support for more than one-fourth of them.** The number of research assistants has risen faster than overall graduate enrollment. A shift is evident away from the physical sciences and into the life sciences, reflecting changes in the field distribution of academic research funds.
- **In most fields, the percentage of academic researchers with Federal support for their work was lower in 2001 than a decade earlier.** Full-time faculty received Federal support less frequently than other full-time doctoral employees, who, in turn, were less frequently supported than postdocs, 74 percent of whom received Federal funds in 2001.
- **In the view of academic researchers, at most a modest shift has taken place during the past decade in the nature of academic R&D.** For both those who identified research as their primary work activity and those who identified it as their primary or secondary activity, the percentage who reported basic research was only slightly smaller in 2001 than in 1993.

Outputs of Scientific and Engineering Research: Articles and Patents

- **The number of U.S. scientific publications has remained essentially flat since 1992, while output has grown strongly in Western Europe and several East Asian countries.** The reasons for the flattening of U.S. output are unknown and are under investigation.
- **Scientific collaboration between institutions has increased significantly over the past 2 decades, particularly between countries.** In 2001, nearly 1 in 5 articles had an international coauthor, compared to 1 in 10 articles in 1988.
- **The United States has the largest share of internationally authored papers and collaborates with the largest number of countries.** The U.S. share, however, has declined as other countries have increased and expanded their ties, mainly with Western Europe, Japan, and several East Asian countries.
- **The S&E literature of the United States is the most widely cited by non-U.S. scientists.** The volume and world share of citations of U.S. S&E literature, however, have been falling as citations of S&E literature from Western Europe and East Asia have increased.
- **The rapid increase in citations of S&E research by U.S. patents suggests the growing importance of science in practical applications of technology.** Over the past 2 decades, citations of research by U.S. patents rose more than 10-fold, primarily because of increases in patents related to the life sciences.
- **More than 3,200 U.S. patents were granted to U.S. academic institutions in 2001, an increase of more than 10-fold since the 1970s.** The bulk of academic patents were granted to a relatively small number of institutions and were highly concentrated in life sciences applications.
- **Increases in licensing income and activity suggest growing effort and success of university commercialization of their products and technology.** Income from licensing was more than $850 million in FY 2001—more than double the amount in FY 1996—and new licenses and options rose by more than half during this period.

Introduction

Chapter Overview

The academic sector is a major contributor to the nation's scientific and technological progress, both through the education and training of scientists and engineers (see chapter 2) and the generation of new knowledge and ideas. These activities advance science and support technological innovation, which in turn enhances economic development. A strong national consensus supports the public funding of academic research, and the Federal Government still provides close to 60 percent of the necessary financial resources, although its role is diminishing. More than half of all academic research and development funds go to the life sciences, and this share increased during the past quarter century, prompting discussion about whether the distribution of funds across disciplines is appropriate.

The number of academic institutions receiving Federal support for R&D activities increased during the past 3 decades, expanding the base of the academic R&D enterprise beyond the traditional research institutions. The academic science and engineering infrastructure, both research space and research equipment, grew over the past decade. However, the percentage of total annual R&D expenditures devoted to research equipment declined.

Doctoral S&E faculty in universities and colleges play a critical role in ensuring an adequate, diverse, and well-trained supply of S&E personnel for all sectors of the economy (see chapter 3). Demographic projections point to the potential for strong enrollment growth and the continuation of several trends: more minority participation, more older students, and more nontraditional students. Future trends for foreign graduate students, however, are uncertain in the wake of the events of September 11, 2001.

In this context, and driven by financial and other pressures, universities and colleges will continue to debate questions about their organization, focus, and mission. These discussions are taking place during a time when academia may be approaching a period of increasing retirements caused by an aging labor force. The extent and nature of replacement hiring into tenure-track faculty positions versus other, more temporary, positions are unresolved questions.

Until recently, positive outcomes and impacts of R&D were taken for granted; however, the R&D enterprise has begun to face demands that it devise means and measures to account for results of specific Federal R&D investments, including those for academic R&D, and for the longer term consequences of those results for valued social ends.[1]

[1]These demands can be seen in both the Government Performance and Results Act (GPRA) of 1993 (Public Law 103-62) and the more recent U.S. Office of Management and Budget R&D Investment Criteria (see http://www.ostp.gov/html/ombguidmemo.pdf). For a discussion of research assessment in the context of the GPRA, see http://www.nsf.gov/sbe/srs/ostp/assess/nstcafse.htm.

This chapter addresses key issues of the academic R&D enterprise, such as the Federal role in supporting academic research; the distribution of funding across S&E disciplines; the breadth and strength of the academic base of the nation's S&E and R&D enterprise; research facilities and instrumentation at universities and colleges; the role of doctoral S&E faculty, including both their teaching and their research responsibilities; and research outputs in the form of refereed articles, academic patents, licenses, and spinoffs. Comparisons with other countries can be found in chapters 2 and 3.

Chapter Organization

The first section of this chapter discusses trends in the financial resources provided for academic R&D, including allocations across both academic institutions and S&E fields. Because the Federal Government has been the primary source of support for academic R&D for more than half a century, the importance of selected agencies in supporting individual fields is explored in detail. This section also presents data on changes in the number of academic institutions that receive Federal R&D support and then examines the status of two key elements of university research activities: facilities and instrumentation.

The next section discusses trends in the employment of academic doctoral scientists and engineers and examines their activities and demographic characteristics. The discussion of employment trends focuses on full-time faculty, postdocs, graduate students, and other positions. Differences between the nation's largest research universities and other academic institutions are considered, as are shifts in the faculty age structure. The involvement of women and minorities is also examined. Attention is given to participation in research by academic doctoral scientists and engineers, the relative balance between teaching and research, and Federal support for research. Selected demographic characteristics of recent doctorate holders entering academic employment are reviewed.

The chapter concludes with an assessment of two types of research outputs: scientific and technical articles measured by data from a set of journals covered by the Science Citation Index (SCI) and the Social Sciences Citation Index (SSCI) and patents issued to U.S. universities. (A third major output of academic R&D, educated and trained personnel, is discussed in the preceding section of this chapter and in chapter 2.) This section looks specifically at the volume of research (article counts), collaboration in the conduct of research (joint authorship), use in subsequent scientific activity (citation patterns), and use beyond science (citations to the literature on patents). It concludes with a discussion of academic patenting and some returns to academic institutions from their patents and licenses.

Financial Resources for Academic R&D

Academic R&D is a significant part of the national R&D enterprise.[2] To carry out world-class research and advance the scientific knowledge base, U.S. academic researchers require financial resources and research facilities and instrumentation that facilitate high-quality work. Several funding indicators bear on the state of academic R&D, including:

- The level and stability of overall funding
- The sources of funding and changes in their relative importance
- The distribution of funding among the different R&D activities (basic research, applied research, and development)
- The distribution of funding among S&E broad and detailed fields
- The distribution of funding among the various performers of academic R&D and the extent of their participation
- The role of the Federal Government as a supporter of academic R&D and the particular roles of the major Federal agencies funding this sector
- The state of the physical infrastructure (research facilities and equipment)

Individually and in combination, these factors influence the evolution of the academic R&D enterprise and therefore are the focus of this section. The main findings are continued growth in both Federal and nonfederal funding of academic R&D, with a steady relative decline in the role of the Federal government; a substantial increase in funding by the National Institutes of Health (NIH) relative to the other main Federal funding agencies; a relative shift in the distribution of funds among fields, with increasing shares for the life sciences, engineering, and the computer sciences; R&D activity occurring in a wider set of institutions, but with the concentration of funds among the top research universities diminishing only slightly; and continuous growth in academic S&E research space, combined with a large fraction of institutions reporting a need for additional space based on current research commitments.

For a discussion of the nature of the data used in this section, see sidebar, "Data Sources for Financial Resources for Academic R&D."

[2]Federally funded research and development centers (FFRDCs) associated with universities are reviewed separately and examined in greater detail in chapter 4. FFRDCs and other national laboratories (including Federal intramural laboratories) also play an important role in academic research and education, providing research opportunities for both students and faculty at academic institutions.

Academic R&D Within the National R&D Enterprise

The continuing importance of academia to the nation's overall R&D effort is well accepted.[3] This is especially true for its contribution to the generation of new knowledge through basic research. Since 1998, academia has accounted for more than half of the basic research performed in the United States.

In 2002, U.S. academic institutions spent an estimated \$36 billion, or \$33 billion in constant 1996 dollars, on R&D.[4] Academia's role as an R&D performer has increased during the past 3 decades, rising from about 10 percent of all R&D performed in the United States in the early 1970s to an estimated 13 percent in 2002 (figure 5-1). (For a comparison with other industrial countries, see sidebar, "Comparisons of International Academic R&D Spending.")

Character of Work

Academic R&D activities are concentrated at the research (basic and applied) end of the R&D spectrum and do not include much development activity.[5] An estimated 96 percent of academic R&D expenditures in 2002 went for research (74 percent for basic and 22 percent for applied) and 4 percent for development (figure 5-2). From the perspective of national research, as opposed to national R&D, academic institutions accounted for an estimated 30 percent of the U.S. total in 2002 (figure 5-1). In terms of basic research alone, the academic sector is the country's largest performer, currently accounting for an estimated 54 percent of the national total. Between the early 1970s and early 1980s, the academic sector's share of basic research declined steadily, from slightly more to slightly less than half of the national total. In the early 1990s, its share of the national total began to increase once again.

Growth

Over the course of the past 3 decades (1972–2002), the average annual R&D growth rate (in constant 1996 dollars) of the academic sector (4.5 percent) has been higher than that of any other R&D-performing sector except the nonprofit sector (5.0 percent). (See figure 5-3 and appendix table 4-4 for time series data by R&D-performing sector.) As a proportion of gross domestic product (GDP), academic R&D rose from 0.23 to 0.35 percent during this time period, about a 50 percent increase. (See appendix table 4-1 for GDP time series.)

[3]For more detailed information on national R&D expenditures, see "National R&D Trends" in chapter 4.

[4]For this discussion, an academic institution is generally defined as an institution that has a doctoral program in science or engineering, is a historically black college or university that expends any amount of separately budgeted R&D in S&E, or is some other institution that spends at least \$150,000 for separately budgeted R&D in S&E.

[5]Despite this delineation, the term *R&D* (rather than just *research*) is primarily used throughout this discussion because data collected on academic R&D do not always differentiate between research and development. Moreover, it is often difficult to make clear distinctions among basic research, applied research, and development. For the definitions used in National Science Foundation resource surveys and a fuller discussion of these concepts, see chapter 4.

Data Sources for Financial Resources for Academic R&D

The data used to describe financial resources for academic research and development are derived from four National Science Foundation (NSF) surveys:

- Survey of Federal Funds for Research and Development
- Survey of Federal Science and Engineering Support to Universities, Colleges, and Nonprofit Institutions
- Survey of Research and Development Expenditures at Universities and Colleges
- Survey of Scientific and Engineering Research Facilities

These surveys use similar but not always identical definitions, and the nature of the respondents also differs across the surveys. The first two surveys collect data from Federal agencies, whereas the last two collect data from universities and colleges.*

Data presented in the context section, "Academic R&D Within the National R&D Enterprise," are derived from special tabulations that aggregate NSF survey data on the various sectors of the U.S. economy so that the components of the overall R&D effort are placed in a national context. These data are reported on a calendar-year basis, and the data for 2001 and 2002 are preliminary. Since 1998, these data also attempt to eliminate double counting in the academic sector by subtracting those current expenditures for separately budgeted science and engineering R&D that do not remain in the institution reporting them but are passed through to other institutions. Data in subsequent sections differ in that they are reported on a fiscal-year basis and do not net out the funds passed through to other institutions. Data on major funding sources, funding by institution type, distribution of R&D funds across academic institutions, and expenditures by field and funding source are from the Survey of Research and Development Expenditures at Universities and Colleges. For various methodological reasons, parallel data by field from the NSF Survey of Federal Funds for Research and Development do not necessarily match these numbers.

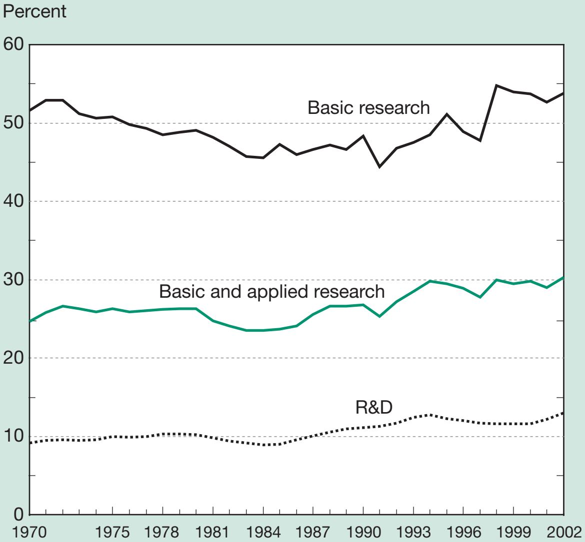
The data in the section "Federal Support of Academic R&D" come primarily from NSF's Survey of Federal Funds for Research and Development. This survey collects data on R&D obligations from 29 Federal agencies. Data for fiscal years 2002 and 2003 are preliminary estimates based on administration budget proposals and do not necessarily represent actual appropriations. Data on Federal obligations by S&E field are available only for FY 2001. These data are not estimated and refer only to research (basic and applied) rather than to research plus development.

The data in the section "Spreading Institutional Base of Federally Funded Academic R&D" are drawn from NSF's Survey of Federal Science and Engineering Support to Universities, Colleges, and Nonprofit Institutions. This survey collects data on Federal R&D obligations to individual U.S. universities and colleges from the approximately 18 Federal agencies that account for virtually all such obligations. For various methodological reasons, data reported in this survey do not necessarily match those reported in the Survey of Research and Development Expenditures at Universities and Colleges.

Data on facilities are taken from the Survey of Scientific and Engineering Research Facilities. This survey is in the midst of a redesign that will broaden its coverage and include computing and networking capacity as well as research space. Data on research equipment are taken from the Survey of Research and Development Expenditures at Universities and Colleges. Although terms are defined specifically in each survey, in general, facilities expenditures are for fixed items such as buildings, are classified as *capital funds,* often cost millions of dollars, and are not included within R&D expenditures as reported here. Research equipment and instruments (the terms are used interchangeably) are generally movable, purchased with current funds, and are included within R&D expenditures reported here. Because the categories are not mutually exclusive, some large instrument systems could be classified as either facilities or equipment. Expenditures for research equipment are limited to current funds and do not include expenditures for instructional equipment. *Current funds,* as opposed to capital funds, are those in the yearly operating budget for ongoing activities. Generally, academic institutions keep separate accounts for current and capital funds.

*For descriptions of the methodologies of the NSF surveys, see NSF/SRS 1995a and 1995b and the Division of Science Resources Statistics website, http://www.nsf.gov/sbe/srs/stats.htm.

Figure 5-1
Academic R&D, basic and applied research, and basic research as share of U.S. total of each category: 1970–2002

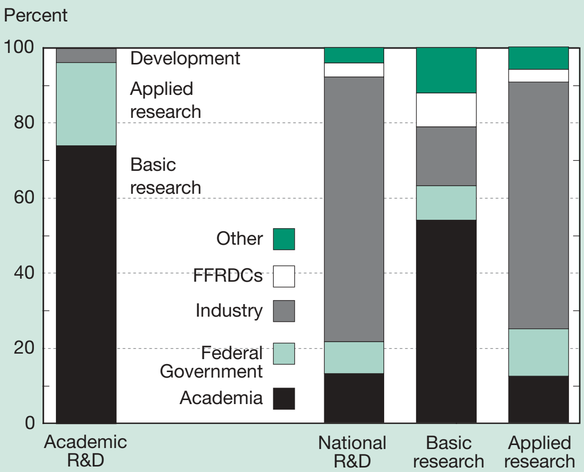


NOTES: Data for 2001 and 2002 are preliminary. Because of changes in estimation procedures, the character of work data before FY 1998 are not comparable with those of later years. For details on methodological issues of measurement, see *The Methodology Underlying the Measurement of R&D Expenditures: 2002* (NSF/SRS, Arlington, VA, forthcoming). Data are based on annual reports by performers. See appendix tables 4-3, 4-7, 4-11, and 4-15 for data underlying the percentages.

SOURCE: National Science Foundation, Division of Science Resources Statistics, *National Patterns of R&D Resources,* annual series. See appendix table 5-1.

Science & Engineering Indicators – 2004

Figure 5-2
Academic R&D expenditures, by character of work, and national R&D expenditures, by performer and character of work: 2002



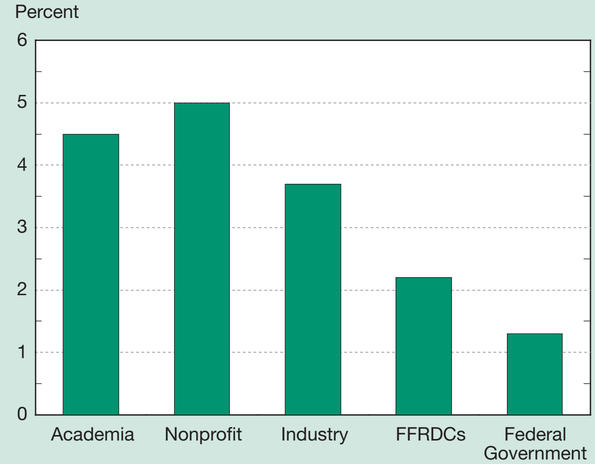
FFRDC federally funded research and development center

NOTE: Data are preliminary.

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 5-1.

Science & Engineering Indicators – 2004

Figure 5-3
Average annual R&D growth, by performer: 1972–2002



FFRDC federally funded research and development center

NOTE: R&D data are on a calendar-year basis. Data for 2001 and 2002 are estimated.

SOURCE: National Science Foundation, Division of Science Resources Statistics, *National Patterns of R&D Resources,* special tabulations. See appendix table 4-4.

Science & Engineering Indicators – 2004

Major Funding Sources

The academic sector relies on a variety of funding sources for support of its R&D activities. Although the Federal Government continues to provide the majority of funds, its share has declined over the past 3 decades, with most of the decline occurring during the 1980s. In 2001, the Federal Government accounted for 59 percent of the funding for R&D performed in academic institutions, compared with 68 percent in 1972 (appendix table 5-2 and figure 5-4).

Federal support of academic R&D is discussed in detail later in this section; the following list summarizes the contributions of other sectors to academic R&D:[6]

- **Institutional funds.** In 2001, institutional funds from universities and colleges constituted the second largest source of funding for academic R&D, accounting for 20 percent, the highest level during the past half century. Institutional funds encompass three categories: separately budgeted funds from unrestricted sources that an academic institution spends on R&D, unreimbursed indirect costs associated with externally funded R&D projects,

[6]The academic R&D funding reported here includes only separately budgeted R&D and institutions' estimates of unreimbursed indirect costs associated with externally funded R&D projects, including mandatory and voluntary cost sharing. It does not include departmental research and thus excludes funds, notably for faculty salaries, for research activities that are not separately budgeted.

Comparisons of International Academic R&D Spending

Countries differ in the proportion of their research and development that is performed at institutions of higher education. Among the countries of the Organisation for Economic Co-operation and Development (OECD), R&D performed in the academic sector, as a proportion of total R&D performance, varied from 9 percent in Slovakia to about 60 percent in Turkey, with an overall OECD average of about 17 percent (table 5-1). The U.S. proportion was about 15 percent. (For international comparisons, university-administered federally funded research and development centers are included in U.S. academic R&D.)

A number of factors may account for the differences in the role academia plays in the performance of R&D from country to country. The structure and organization of a country's education system will influence how much R&D is performed in the academic sector. The distribution of a country's R&D expenditures among basic research, applied research, and development is likely to affect the share performed by higher education. Because the academic sector primarily carries out research (generally basic) rather than development activities, countries in which development activities take greater prominence may rely less on the academic sector for overall R&D performance. The importance and strength of other sectors, particularly the industrial sector, in R&D performance also may affect the academic sector's share. (See "International R&D by Performer, Source, and Character of Work" in chapter 4 for more detailed information, including data on the sources of funding for academic R&D in different countries.) Institutional and cultural factors such as the role and extent of independent research institutions, national laboratories, and government-funded or -operated research centers, would also affect the academic sector's share.

Finally, different accounting conventions among countries may account for some of the differences reported. For instance, the national totals for academic R&D for Europe and Canada include the research components of general university funds (GUF) provided as block grants to the academic sector by all levels of government. Therefore, at least conceptually, the totals include academia's separately budgeted research and research undertaken as part of university departmental research activities. In the United States, the Federal Government generally does not provide research support through a GUF equivalent, preferring instead to support specific, separately budgeted R&D projects. On the other hand, some state government funding probably does support departmental research at U.S. public universities. Universities generally do not maintain data on departmental research, which is considered an integral part of instruction programs. U.S. totals thus may be underestimated relative to the academic R&D efforts reported for other countries. Other accounting differences include the inclusion or exclusion of R&D in the social sciences and humanities, the inclusion or exclusion of defense R&D, treatment of capital expenditures, and the level of government included.

Table 5-1
Academic R&D share of total R&D performance, by selected countries: 2000 or 2001
(Percent)

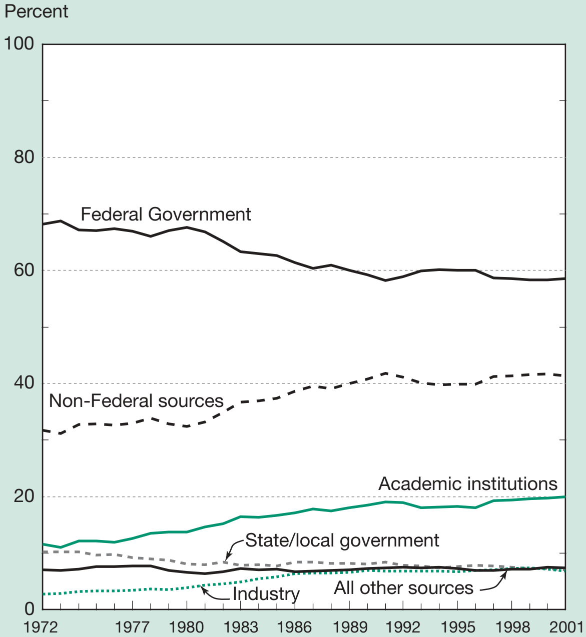
Country	Academic R&D
All OECD	17.2
Australia	27.1
Canada	32.7
Czech Republic	15.7
Finland	17.9
France	18.5
Germany	15.8
Hungary	24.0
Iceland	15.5
Italy	31.0
Japan	14.5
Netherlands	28.8
Poland	32.7
Slovakia	9.0
South Korea	11.3
Spain	29.4
Switzerland	22.9
Turkey	60.4
United Kingdom	20.8
United States	14.9
Non-OECD	
Argentina	35.0
China	8.6
Israel	18.4
Romania	11.3
Russia	5.2
Singapore	23.6
Slovenia	16.6
Taiwan	12.2

OECD Organisation for Economic Co-operation and Development

SOURCE: OECD, *Main Science and Technology Indicators,* 2002. See appendix table 4-45.

Science & Engineering Indicators – 2004

Figure 5-4
Sources of academic R&D funding: 1972–2001



SOURCES: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), *Academic Research and Development Expenditures: Fiscal Year 2001,* 2003; and NSF/SRS, WebCASPAR database system, http://caspar.nsf.gov. See appendix table 5-2.

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and mandatory and voluntary cost sharing on Federal and other grants. For more detailed discussions of the composition of institutional funds, see sidebar "The Composition of Institutional Academic R&D Funds."

The share of support represented by institutional funds has been increasing during the past 3 decades, except for a brief downturn in the early 1990s. Institutional R&D funds may be derived from (1) general-purpose state or local government appropriations (particularly for public institutions) or Federal appropriations; (2) general-purpose grants from industry, foundations, or other outside sources; (3) tuition and fees; (4) endowment income; and (5) unrestricted gifts. Other potential sources of institutional funds are income from patents or licenses and income from patient care revenues. (See "Patents Awarded to U.S. Universities" later in this chapter for a discussion of patent and licensing income.)

- **State and local government funds.** State and local governments provided 7.1 percent of academic R&D funding in 2001. Since 1980, the state and local share of academic R&D funding has remained between 7 and 9 percent. This share, however, only reflects funds directly targeted to academic R&D activities by state and local governments. It does not include general-purpose state or local government appropriations that academic institutions designate and use to fund separately budgeted research or cover unreimbursed indirect costs.[7] Consequently, the actual contribution of state and local governments to academic R&D is not captured here, particularly for public institutions. See chapter 8, "State Indicators" for some indicators of academic R&D by state.
- **Industry funds.** In 2001, industry provided 6.8 percent of academic R&D funding, a slight decline from its peak of 7.4 percent in 1999. Despite the recent decline, the funds provided for academic R&D by the industrial sector grew faster than funding from any other source during the past 3 decades. However, industrial support still accounts for one of the smaller shares of funding, and support of academia has never been a major component of industry-funded R&D. In 1994, industry's contribution to academic R&D represented 1.5 percent of its total support of R&D, compared with 1.4 percent in 1990, 0.9 percent in 1980, and 0.7 percent in 1972. Between 1994 and 2000, this share declined from 1.5 to 1.2 percent, before beginning to rise slightly again in both 2001 and 2002. (See appendix table 4-4 for time series data on industry-funded R&D and the sidebar "Corporate R&D Strategies in an Uncertain Economy" in chapter 4 for a discussion of how companies intend to spend their R&D budgets.)
- **Other sources of funds.** In 2001, other sources of support accounted for 7.4 percent of academic R&D funding, a level that has stayed almost constant during the past 3 decades. This category of funds includes grants for R&D from nonprofit organizations and voluntary health agencies and gifts from private individuals that are restricted by the donor to the conduct of research, as well as all other sources restricted to research purposes not included in the other categories.

Funding by Institution Type

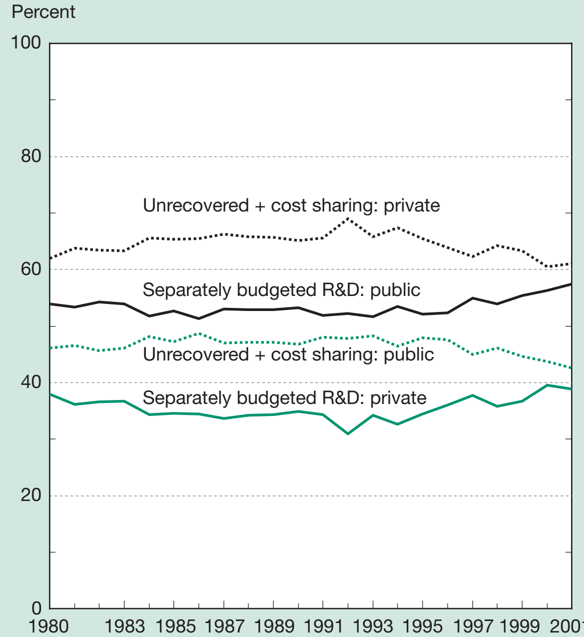
Although public and private universities rely on the same funding sources for their academic R&D, the relative importance of those sources differs substantially for these two types of institutions (figure 5-5 and appendix table 5-3). In 2001, the most recent year for which data are available, just over 9 percent of R&D funding for all public academic institutions came from state and local funds, about 25 percent from institutional funds, and about 52 percent from the Federal Government. Private academic institutions received a much smaller portion of their funds from state and local governments (about 2 percent) and institutional sources (about 10 percent), and a much larger share from the Federal Government (72 percent). The large difference in the role of institutional funds at public and private institutions is most likely because of a substantial amount of general-purpose state and local government funds that public institutions receive and decide to use for R&D (although data on such

[7]This follows a standard of reporting that assigns funds to the entity that determines how they are to be used rather than to the one that necessarily disburses the funds.

The Composition of Institutional Academic R&D Funds

During the past 3 decades, institutional funds for academic R&D grew faster than funds from any other sources except industry and faster than any other source since 1990 (appendix table 5-2). In 2001, academic institutions committed a substantial amount of their own resources to R&D: roughly $6.5 billion, or 20 percent of total academic R&D. In 2001, the share of institutional support for academic R&D at public institutions (25 percent) was greater than at private institutions (10 percent) (appendix table 5-3). One possible reason for this large difference in relative support is that public universities and colleges' own funds may include considerable state and local funds not specifically designated for R&D but used for that purpose by the institutions. Throughout the 1980s and 1990s, institutional R&D funds were divided roughly equally between two components: separately budgeted institutional R&D funds and mandatory and voluntary cost sharing plus unreimbursed indirect costs associated with R&D projects financed by external organizations. Institutional funds at public and private universities and colleges differ not only in their importance to the institution but also in their composition. Since 1980, from 60 to 70 percent of private institutions' own funds were designated for unreimbursed indirect costs plus cost sharing compared with 43 to 49 percent of public institutions' own funds (figure 5-6).

Figure 5-6
Components of institutional R&D expenditures for public and private academic institutions: 1980–2001



SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Research and Development Expenditures at Universities and Colleges, special tabulations.

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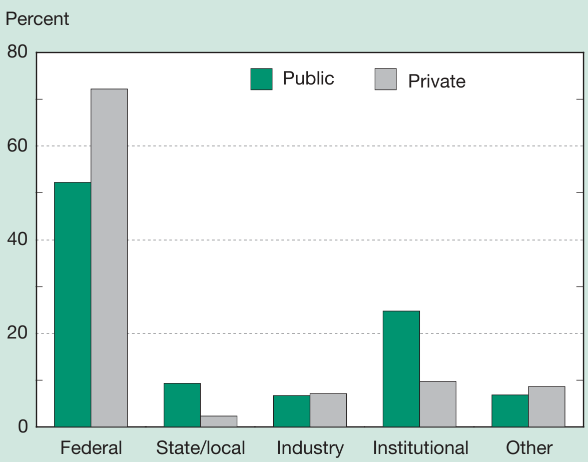
Figure 5-5
Sources of academic R&D funding for public and private institutions: 2001



SOURCES: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), *Academic Research and Development Expenditures: Fiscal Year 2001,* 2003; and NSF/SRS, WebCASPAR database system, http://caspar.nsf.gov. See appendix table 5-3.

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breakdowns are not collected). Both public and private institutions received approximately 7 percent of their respective R&D support from industry in 2001. Over the past 2 decades, the Federal share of support has declined, and the industry and institutional shares increased for both public and private institutions.

Distribution of R&D Funds Across Academic Institutions

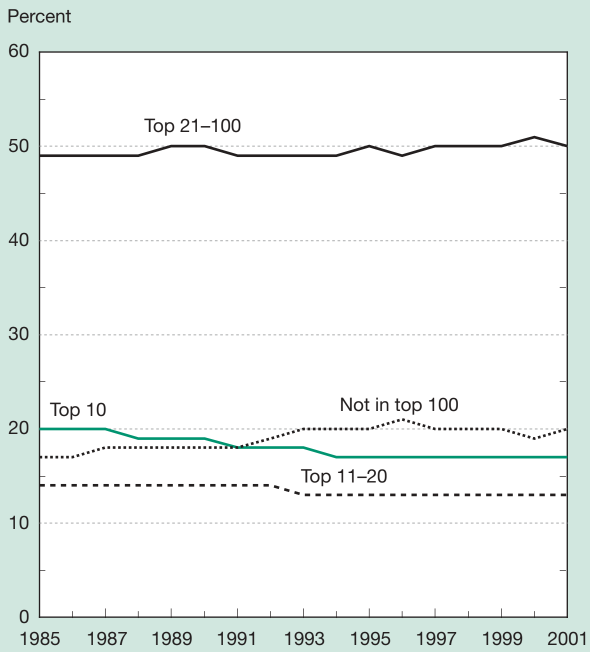
The nature of the distribution of R&D funds across academic institutions has been and continues to be a matter of interest to both those concerned with the academic R&D enterprise and those concerned with local and regional economic development. Most academic R&D is now, and has been historically, concentrated in relatively few of the 3,600 U.S. institutions of higher education.[8] When institutions are

[8]The Carnegie Foundation for the Advancement of Teaching classified about 3,600 degree-granting institutions as higher education institutions in 1994. See chapter 2 sidebar, "Carnegie Classification of Academic Institutions," for a brief description of the Carnegie categories. These higher education institutions include 4-year colleges and universities, 2-year community and junior colleges, and specialized schools such as medical and law schools. Not included in this classification scheme are more than 7,000 other postsecondary institutions (secretarial schools, auto repair schools, etc.).

ranked by their 2001 R&D expenditures, the top 200 institutions account for about 96 percent of all 2001 R&D expenditures. (See appendix table 5-4 for a more detailed breakdown of the distribution among the top 100 institutions.)

The historic concentration of academic R&D funds diminished between the mid-1980s and mid-1990s but has remained relatively steady since then (figure 5-7). In 1985, the top 10 institutions received about 20 percent of the nation's total academic R&D expenditures and the top 11–20 institutions received 14 percent, compared with 17 and 13 percent, respectively, in 2001. There was almost no change in the share of the group of institutions ranked 21–100 during this period. The composition of the universities in any particular group is not necessarily the same over time, because mobility occurs within groups. For example, only 5 of the top 10 institutions in 1985 were still in the top 10 in 2001. The decline in the top 20 institutions' share was offset by an increase in the share of those institutions in the group not in the top 100. This group's share increased from 17 to 20 percent of total academic R&D funds, signifying a broadening of the base. The discussion in "Spreading Institutional Base of Federally Funded Academic R&D" later in this chapter, under the section "Federal Support of Academic R&D," points to an increasing number of academic institutions receiving Federal support for their R&D activities during the past 3 decades. Many of the newer institutions receiving support are not the traditional research and doctorate-granting institutions.

Figure 5-7
Academic R&D, by rank of universities' and colleges' academic R&D expenditures: 1985–2001



SOURCES: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), *Academic Research and Development Expenditures: Fiscal Year 2001,* 2003, special tabulations; and NSF/SRS, WebCASPAR database system, http://caspar.nsf.gov. See appendix table 5-4.

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Expenditures by Field and Funding Source

The distribution of academic R&D funds across S&E disciplines often is the result of numerous, sometimes unrelated, funding decisions rather than an overarching plan. Examining and documenting academic R&D investment patterns across disciplines enables interested parties to assess the balance in the academic R&D portfolio. The majority of expenditures for academic R&D in 2001 went to the life sciences, which accounted for 59 percent of all academic R&D expenditures, 58 percent of Federal academic R&D expenditures, and 59 percent of non-Federal academic R&D expenditures (appendix table 5-5). Within the life sciences, the medical sciences accounted for about 31 percent of academic R&D expenditures and the biological sciences for about 18 percent.[9] The next largest block of academic R&D expenditures went to engineering, with about 15 percent in 2001.

The distribution of Federal and non-Federal expenditures for academic R&D in 2001 varied by field (appendix table 5-5). For example, the Federal Government provided about three-fourths of the academic R&D expenditures in both physics and atmospheric sciences but one-third or less of those in economics, political science, and the agricultural sciences.

The decline in the Federal share of academic R&D support is not limited to particular S&E disciplines. The federal share of support for each of the broad S&E fields was lower in 2001 than in 1975 (appendix table 5-6).[10] The most dramatic decline occurred in the social sciences, down from about 55 percent in 1975 to about 38 percent in 2001. The overall decline in Federal share also holds for all the reported S&E detailed fields. However, most of the declines occurred in the 1980s, and many fields did not experience declining Federal shares during the 1990s.

Although the total expenditures for academic R&D in constant 1996 dollars increased in every field between 1975 and 2001 (figure 5-8 and appendix table 5-7), the R&D emphasis of the academic sector, as measured by its S&E field shares, changed during this period (figure 5-9). Relative shares of academic R&D:

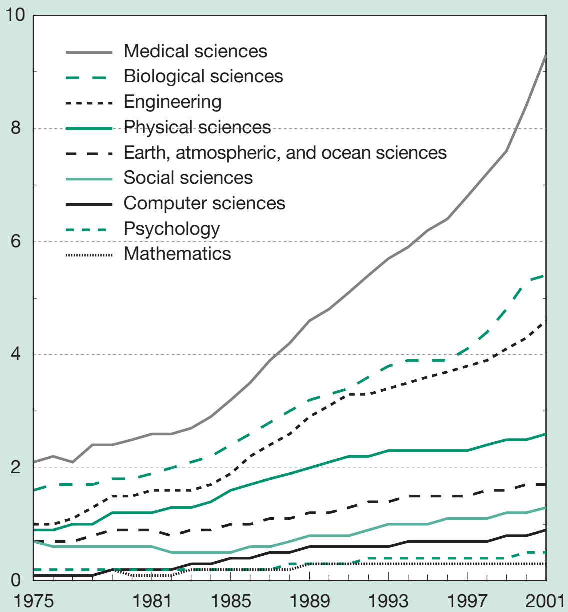
- Increased for engineering, the life sciences, and the computer sciences
- Remained roughly constant for mathematics
- Declined for psychology; the earth, atmospheric, and ocean sciences; the physical sciences; and the social sciences

[9]The medical sciences include fields such as pharmacy, veterinary medicine, anesthesiology, and pediatrics. The biological sciences include fields such as microbiology, genetics, biometrics, and ecology. These distinctions may be blurred at times, because boundaries between fields often are not well defined.

[10]In this chapter, the *broad* S&E fields refer to the physical sciences; mathematics; computer sciences; earth, atmospheric, and ocean sciences; life sciences; psychology; social sciences; other sciences (not elsewhere classified); and engineering. The more disaggregated fields of S&E are referred to as *detailed fields*.

Figure 5-8
Academic R&D expenditures, by field: 1975–2001

Billions of constant 1996 U.S. dollars



NOTE: See appendix table 4-1 for gross domestic product implicit price deflators used to convert current dollars to constant 1996 dollars.

SOURCES: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), *Academic Research and Development Expenditures: Fiscal Year 2001,* 2003; and NSF/SRS, WebCASPAR database system, http://caspar.nsf.gov. See appendix table 5-7.

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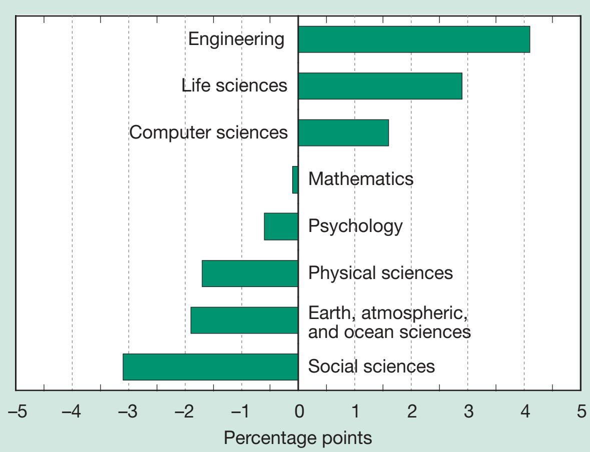
Figure 5-9
Change in share of academic R&D in selected S&E fields: 1975–2001



SOURCES: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), *Academic Research and Development Expenditures: Fiscal Year 2001,* 2003; and NSF/SRS, WebCASPAR database system, http://caspar.nsf.gov. See appendix table 5-7.

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Although the proportion of all academic R&D funds going to the life sciences increased by only 3 percentage points (from 55.8 to 58.6 percent) between 1975 and 2001, the medical sciences' share increased by more than 7 percentage points (from 23.8 to 31.1 percent) during this period (appendix table 5-7). In the biological sciences, the share of funds was about the same at the beginning and end of the period, whereas in the agricultural sciences, the other major component of the life sciences, the share decreased. Engineering's share of academic R&D increased by about 4 percentage points (from 11.2 to 15.3 percent), whereas the computer sciences' share more than doubled (from 1.3 to 2.9 percent).

The social sciences' proportion of all academic R&D funds declined by more than 3 percentage points (from 7.5 to 4.4 percent) between 1975 and 2001. Within the social sciences, R&D shares for each of the three main fields (economics, political science, and sociology) declined over the period. Psychology's share declined from 2.4 to 1.8 percent. The earth, atmospheric, and ocean sciences' overall share declined by about 2 percentage points (from 7.5 to 5.6 percent), with each of the three detailed fields (atmospheric sciences, earth sciences, and ocean sciences) experiencing an individual decline in share. The physical sciences' overall share also declined during this period (from 10.3 to 8.6 percent). Within the physical sciences, the shares of both physics and chemistry declined, although astronomy's share increased.

Federal Support of Academic R&D

The Federal Government continues to provide the majority of the funding for academic R&D. Its overall contribution is the combined result of a complex set of executive and legislative branch decisions to fund a number of key R&D-supporting agencies with differing missions. Some of the Federal R&D funds obligated to universities and colleges are the result of appropriations that Congress directs Federal agencies to award to projects that involve specific institutions. These funds are known as congressional earmarks. (See sidebar, "Congressional Earmarking to Universities and Colleges.") Examining and documenting the funding patterns of the key funding agencies is key to understanding both their roles and that of the Federal Government overall.

Top Supporting Agencies

Six agencies are responsible for most of the Federal obligations for academic R&D, providing an estimated 96 percent of such obligations in FY 2003 (appendix table 5-8).[11] NIH provided approximately 66 percent of total Federal financing of

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[11]The recent creation of the Department of Homeland Security (DHS) should have major implications for the future distribution of Federal R&D funds, including Federal academic R&D support, among the major R&D funding agencies. DHS's Science & Technology directorate is tasked with researching and organizing the scientific, engineering, and technological resources of the United States and leveraging these existing resources into technological tools to help protect the homeland. Universities, the private sector, and the Federal laboratories are expected to be important partners in this endeavor.

Congressional Earmarking to Universities and Colleges

Academic earmarking, the congressional practice of providing Federal funds to educational institutions for research facilities or projects without merit-based peer review, passed the billion-dollar mark for the first time ever in fiscal year 2000, reached almost $1.7 billion in FY 2001, and exceeded $1.8 billion in FY 2002 (table 5-2). However, not all of these funds go to projects that involve research. The *Chronicle of Higher Education* estimated that 84 percent of earmarked funds in FY 2001 and 87 percent in FY 2002 were for research projects, research equipment, or construction or renovation of research laboratories (Brainard 2002).

Obtaining exact figures for either the amount of funds or the number of projects specifically earmarked for universities and colleges, either overall or for research, is often difficult because of the lack of an accepted definition of academic earmarking and because the funding legislation is often obscure in its description of the earmarked projects. Even with these difficulties, however, a number of efforts were undertaken during the past 2 decades to measure the extent of this activity. Several of these efforts are discussed below.

A report from the Committee on Science, Space, and Technology (U.S. House of Representatives 1993) estimating trends in congressional earmarking indicated that the dollar amount of such earmarks increased from the tens to the hundreds of millions between 1980 and the early 1990s, reaching $708 million in 1992 (table 5-2). In the report, the late Congressman George E. Brown, Jr., (D-CA) stated, “I believe that the rational, fair, and equitable allocation and oversight of funds in support of the nation’s research and development enterprise is threatened by the continued increase in academic earmarks. To put it colloquially, a little may be okay, but too much is too much.”

During the past decade, the *Chronicle of Higher Education* also tried to estimate trends in academic earmarking through an annual survey of Federal spending laws and the congressional reports that explain them. The Chronicle’s latest analysis showed that after reaching a peak of $763 million in 1993, earmarked funds declined more than 60 percent over the next 3 years, reaching a low of $296 million in FY 1996. After 1996, however, earmarks began to increase once again. Congress directed Federal agencies to award at least $1.837 billion for such projects in FY 2002. A record number of institutions received earmarks in FY 2002.

The Office of Management and Budget (OMB) has also recently attempted to provide budget estimates of earmarked funds. In its FY 2001 budget submission to Congress, OMB included a new category of Federal funding for research: research performed at congressional direction (OMB 2002). This consists of intramural and extramural research in which funded activities are awarded to a single performer or collection of performers. Competitive selection is limited or nonexistent, or, where there is competitive selection, the research is outside the agency’s primary mission and being undertaken at Congress’ direction via legislation, report language, or other means. The total reported for this activity is about $2 billion in both FY 2001 and FY 2002. The data are not disaggregated by type of performer.

Finally, the American Association for the Advancement of Science (AAAS) has also recently undertaken an effort to identify congressionally designated, performer-specific R&D projects not appearing in agency budget requests (AAAS 2003). AAAS estimates that R&D earmarks totaled $1.4 billion in FY 2003, down slightly from the FY 2002 estimate of $1.5 billion. Although these estimates include earmarks to all types of R&D performers, the bulk of them are assumed to go to academic institutions.

Given the difficulties in defining and identifying earmarks discussed earlier, it is informative that the recent estimates by the *Chronicle,* OMB, and AAAS are of the same order of magnitude. The estimates indicate that in recent years, about 5 to 6 percent of all academic R&D funds were earmarked.

Table 5-2
Funds for congressionally earmarked academic research projects: 1980–2002
(Millions of dollars)

Year	Earmarked funds
1980	11
1981	0
1982	9
1983	77
1984	39
1985	104
1986	111
1987	163
1988	232
1989	299
1990	248
1991	470
1992	708
1993	763
1994	651
1995	600
1996	296
1997	440
1998	528
1999	797
2000	1,044
2001	1,668
2002	1,837

SOURCES: 1980–92: U.S. House of Representatives, *Academic Earmarks: An Interim Report by the Chairman of the Committee on Science, Space, and Technology* (Washington, DC, 1993); 1993–2000: *Chronicle of Higher Education* 46:A29 (July 28, 2000), 47:A20 (August 10, 2001), and 49:A20 (September 27, 2002).

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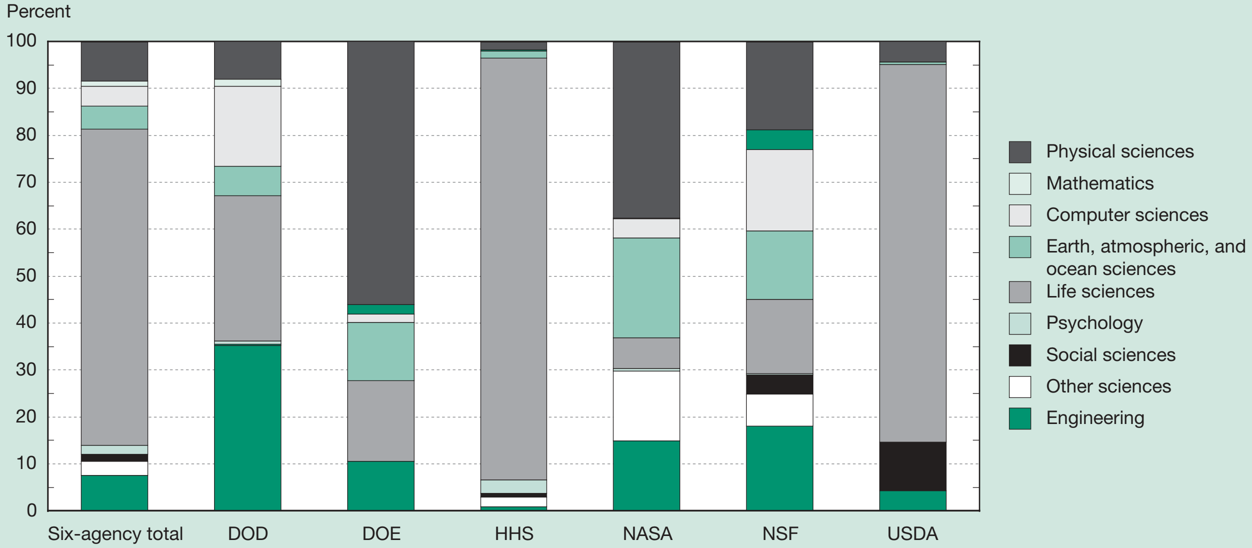
Figure 5-10
Federal agency academic research obligations, by field: FY 2001



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: Agencies reported represent approximately 97 percent of Federal academic research obligations.

SOURCE: National Science Foundation, Division of Science Resources Statistics, *Federal Funds for Research and Development: Fiscal Years 2001, 2002, and 2003,* forthcoming. See appendix table 5-10.

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academic R&D in 2003. An additional 12 percent was provided by NSF, 8 percent by DOD, 4 percent by the National Aeronautics and Space Administration (NASA); 3 percent by the Department of Energy (DOE); and 2.5 percent by the Department of Agriculture (USDA). The concentration of Federal obligations for academic research is similar to that for R&D (appendix table 5-9). Some differences exist, however, because some agencies place greater emphasis on development (e.g., DOD), whereas others place greater emphasis on research (e.g., NSF).

Between 1990 and 2003, NIH's funding of academic R&D increased the most rapidly, with an estimated average annual growth rate of 7.2 percent per year in constant 1996 dollars, increasing its share of Federal funding from just above 50 percent to an estimated 66 percent. NSF and NASA experienced the next highest rates of growth: 3.8 and 3.4 percent, respectively.

Agency Support by Field

Federal agencies emphasize different S&E fields in their funding of academic research. Several agencies concentrate their funding in one field. The Department of Health and Human Services (HHS) and USDA focus on life sciences, whereas DOE concentrates on the physical sciences. The funding patterns of other agencies, such as NSF, NASA, and DOD, are more diversified (figure 5-10 and appendix table 5-10).

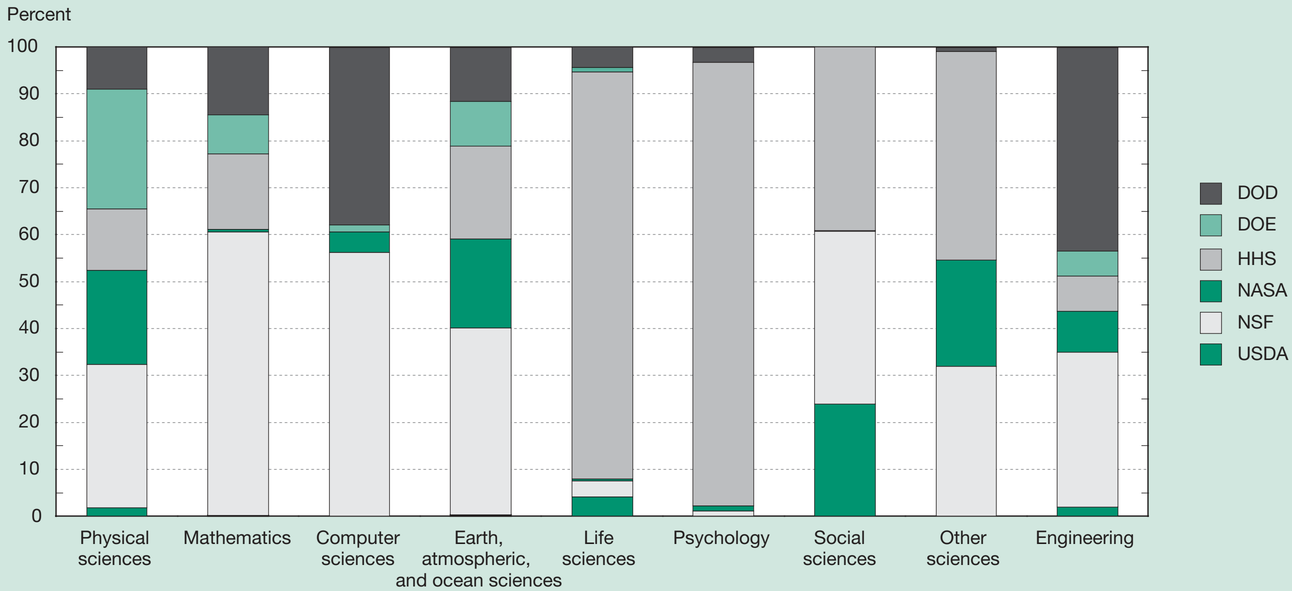
An agency may allocate a large share of its funds to one field yet not be a leading contributor to that field, particularly if it does not spend much on academic research (figure 5-11). In FY 2001, NSF was the lead funding agency in physical sciences (30.6 percent of total funding), mathematics (60 percent), computer sciences (56 percent), and earth, atmospheric, and ocean sciences (40 percent). DOD was the lead funding agency in engineering (43 percent). HHS was the lead funding agency in life sciences (87 percent), psychology (95 percent), and social sciences (39 percent). Within S&E detailed fields, other agencies took the leading role: DOE in physics (50 percent), USDA in agricultural sciences (99 percent), and NASA in astronomy (81 percent) and astronautical engineering (87 percent) (appendix table 5-11).

Spreading Institutional Base of Federally Funded Academic R&D

The number of academic institutions receiving Federal support for their R&D activities has generally increased during the past 3 decades. However, between 1994 and 2000, the number receiving support declined slightly before increasing again in 2000 (figure 5-12).[12] The change in the number supported has occurred almost exclusively among institutions of higher education with Carnegie classifications of comprehensive; liberal arts; 2-year community, junior, and technical; and professional and other specialized schools, rather than among those classified as research or

[12]Although the number of institutions receiving Federal R&D support generally increased between 1973 and 1994, a rather large decline occurred in the early 1980s, most likely caused by the decrease in Federal R&D funding for the social sciences during that period.

Figure 5-11
Major agency shares of Federal academic research obligations, by field: FY 2001



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: Agencies reported represent approximately 97 percent of Federal academic research obligations.

SOURCE: National Science Foundation, Division of Science Resources Statistics, *Federal Funds for Research and Development: Fiscal Years 2001, 2002, and 2003*, forthcoming. See appendix table 5-11.

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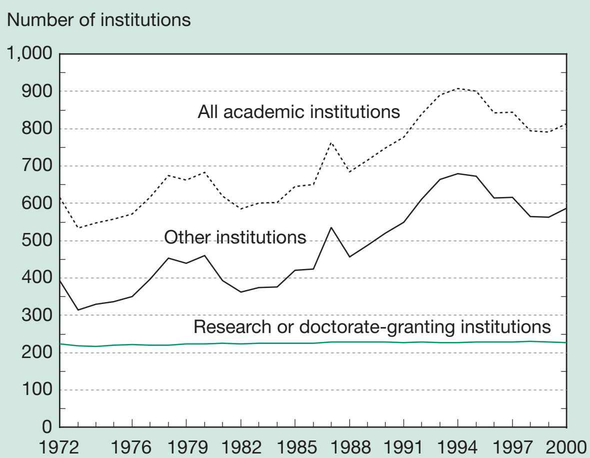
Figure 5-12
Academic institutions receiving Federal R&D support, by selected Carnegie classifications: 1972–2000



NOTES: Other institutions include all institutions except Carnegie research and doctorate-granting institutions. Institutions are designated by the 1994 Carnegie classification code. See Carnegie Foundation for the Advancement of Teaching, *A Classification of Institutions of Higher Education* (Princeton, NJ: Princeton University Press, 1994). For more information on these categories, see chapter 2, "Carnegie Classification of Academic Institutions."

SOURCES: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), *Federal Science and Engineering Support to Universities, Colleges, and Nonprofit Institutions: Fiscal Year 2001,* forthcoming; and NSF/SRS, WebCASPAR database system, http://caspar.nsf.gov. See appendix table 5-12.

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doctorate-granting institutions. The number of such institutions receiving Federal support more than doubled between 1973 and 1994, rising from 315 to 680, but then dropped to 587 in 2000 (appendix table 5-12). These institutions' share of Federal support also increased between 1973 and 1994, from about 10 percent to above 13 percent. Their share even continued to increase after 1994, reaching just over 15 percent in 2000.

Academic R&D Facilities and Equipment

The condition of the physical infrastructure for academic R&D, especially the state of research facilities and equipment, is a key factor in the continued success of the U.S. academic R&D enterprise.[13]

[13]An important element of research infrastructure, *cyberinfrastructure,* is not discussed in this report but will be discussed in future editions as more information about this important component becomes available. A recent report has concluded that continuing progress in computing, information, and communication technology has made possible a cyberinfrastructure on which to build new types of S&E knowledge environments and organizations and to pursue research in new ways and with increased efficacy (NSF 2003).

Facilities

Total Space. The amount of academic S&E research space[14] grew continuously between 1988 and 2001. During this period, total academic S&E research space increased by more than 38 percent, from about 112 to 155 million net assignable square feet.[15]

The distribution of academic research space across S&E fields changed only slightly between 1988 and 2001 (appendix table 5-13). About 90 percent of current academic research space continues to be concentrated in six S&E fields:

- Biological sciences (21 percent in 1988 and 2001)
- Medical sciences (17 percent in 1988 and 18 percent in 2001)
- Agricultural sciences (16 percent in 1988 and 17 percent in 2001)
- Engineering (14 percent in 1988 and 17 percent in 2001)
- Physical sciences (14 percent in 1988 and 12 percent in 2001)
- Earth, atmospheric, and ocean sciences (6 percent in 1988 and 5 percent in 2001).

Adequacy. Survey respondents were asked to rate the adequacy of their research space in 2001.[16] Slightly less than 30 percent of S&E research space was rated as adequate (table 5-3). However, the adequacy of this space differed across S&E fields. The fields with the largest proportion of research space reported as adequate were mathematics (69 percent); social sciences (39 percent); earth, atmospheric, and ocean sciences (38 percent); and psychology (37 percent). Those with the smallest proportion were engineering and medical sciences (each with about 23 percent).

Of the institutions reporting research space in 2001, more than 80 percent reported needing additional space in at least one field.[17] More than 60 percent reported needing additional space in the biological sciences (both in universities and colleges and medical schools), the medical sciences (but only in medical schools), and engineering. In all of these fields (as well as some others), more than 38 percent of these institutions reported needing additional space equal to more than 25 percent of their current research space (table 5-4). Only in mathematics did less than half of the institutions report needing any additional space, although, as noted below, those that reported a need for space needed a relatively large quantity of space as compared with their available space.

For all fields combined, the additional space reported as needed was more than one-fourth of available S&E research space in 2001. For most fields, the additional space needed was between 25 and 35 percent of currently available research space (table 5-3). For computer sciences and mathematics, however, it was approximately 109 and 69 percent, respectively. For the agricultural sciences, the additional space reported as needed was about 11 percent of available space.

Equipment

Expenditures. In 2001, slightly less than $1.5 billion in current funds was spent for academic research equipment. About 83 percent of these expenditures were concentrated in three fields: life sciences (45 percent), engineering (22 percent), and physical sciences (16 percent) (figure 5-13 and appendix table 5-14).

Current fund expenditures for academic research equipment grew at an average annual rate of 4.1 percent (in constant 1996 dollars) between 1983 and 2001. Average annual growth, however, was much higher during the 1980s (7.8 percent) than it was after 1990 (1.9 percent). The growth patterns in S&E fields varied during this period. For example, equipment expenditures for engineering (5.5 percent) and biological sciences (5 percent) grew more rapidly during the 1983–2001 period than did those for the social sciences (0.6 percent) and psychology (1.7 percent).

Federal Funding. Federal funds for research equipment are generally received either as part of research grants, thus enabling the research to be performed, or as separate equipment grants, depending on the funding policies of the particular Federal agency involved. The importance of Federal funding for research equipment varies by field. In 2001, the social sciences received slightly less than 40 percent of their research equipment funds from the Federal Government; in contrast, Federal support accounted for more than 60 percent of equipment funding in the physical sciences; computer sciences; earth, atmospheric, and ocean sciences; and psychology (appendix table 5-15).

The share of research equipment expenditures funded by the Federal Government declined from about 62 to 55 percent between 1983 and 2001, although not consistently. This overall pattern masks different trends in individual S&E fields. For example, the share funded by the Federal Government actually rose during this period for both the social and the earth, atmospheric, and ocean sciences.

R&D Equipment Intensity. R&D equipment intensity is the percentage of total annual R&D expenditures from current funds devoted to research equipment. This propor-

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[14]In addition to examining the amount and adequacy of research space, past volumes of *Indicators* also looked at a number of other issues, including new construction, repair and renovation, condition of research space, and unmet needs. However, the 2001 Survey of Scientific and Engineering Research Facilities was limited in scope and did not cover many of the elements covered in previous surveys. A redesigned survey with a broader scope is being planned. In addition to collecting data on research space, the redesigned survey will also include a section on computing and networking capacity. For earlier information, see *Science and Engineering Indicators – 2002* (NSB 2002) and *Scientific and Engineering Research Facilities: 1999* (NSF/SRS 2001).

[15]*Research space* here refers to net assignable square feet (NASF) within facilities (buildings) in which S&E research activities take place. NASF is defined as the sum of all areas (in square feet) on all floors of a building assigned to, or available to be assigned to, an occupant for a specific use, such as instruction or research. Multipurpose space within facilities (e.g., an office) is prorated to reflect the proportion of use devoted to research activities. NASF data on total space are reported at the time of the survey.

[16]The following definitions were used in the survey: *adequate,* sufficient amount of space to support all the needs of current S&E research program commitments in the field; *inadequate,* insufficient space to support the needs of current S&E research program commitments in the field, or nonexistent but needed; and *not applicable,* no space reported.

[17]Survey respondents who indicated that the amount of space in a field was inadequate were requested to report the amount of additional space needed. Therefore, additional space needed in a field was intended to reflect space needed for current S&E research commitments in that field.

Table 5-3
Status of academic S&E research space, by field: 2001

	Available space	Space reported adequate		Space needed	
Field	Millions NASF	Millions NASF	Percent	Millions NASF	Percent[a]
All fields	147.5	42.7	29.0	40.4	27.4
Physical sciences	18.3	5.9	32.5	4.6	24.9
Mathematics	0.9	0.6	68.8	0.6	69.1
Computer sciences	2.1	0.6	26.9	2.2	108.5
Earth, atmospheric, and ocean sciences	7.7	2.9	37.5	2.0	25.7
Agricultural sciences	25.6	7.6	29.8	2.7	10.6
Biological sciences	31.9	8.5	26.6	10.0	31.5
Universities and colleges	19.4	4.5	23.1	5.7	29.3
Medical schools	12.4	4.0	32.0	4.3	34.9
Medical sciences	26.3	6.0	22.8	9.0	34.1
Universities and colleges	7.5	2.4	32.5	2.1	28.3
Medical schools	18.8	3.5	18.9	6.8	36.4
Psychology	3.4	1.3	37.0	1.1	31.3
Social sciences	4.3	1.7	38.5	1.5	34.3
Other sciences	2.8	2.0	71.8	0.5	17.5
Engineering	24.2	5.7	23.3	6.2	25.7

NASF net assignable square feet

[a]Percent of available space.

NOTES: Values for available research space do not match national totals because data were not imputed for the question on adequacy. Available space is calculated only for institutions that responded to the adequacy question. Details may not add to totals because of rounding. Percents are based on unrounded numbers.

SOURCE: National Science Foundation, Division of Science Resources Statistics, *Scientific and Engineering Research Facilities: 2001,* NSF 02-307 (Arlington, VA, 2002).

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Table 5-4
Institutions reporting need for additional S&E research space, by field: 2001
(Percent)

		Space needed[a]			
Field	None	Total	Less than 10	10–25	More than 25
All fields	17.7	82.3	13.3	18.3	50.7
Physical sciences	40.6	59.4	7.4	10.8	41.2
Mathematics	60.9	39.1	2.2	4.1	32.8
Computer sciences	43.3	56.7	1.6	3.5	51.6
Earth, atmospheric, and ocean sciences	47.7	52.3	6.5	10.1	35.7
Agricultural sciences	43.0	57.0	19.6	8.4	29.0
Biological sciences					
Total	33.8	66.2	8.8	12.5	44.9
Universities & colleges	37.1	62.9	7.7	11.1	44.1
Medical schools	33.7	66.3	8.2	14.5	43.6
Medical sciences					
Total	39.6	60.4	5.4	14.4	40.6
Universities & colleges	48.0	52.0	5.7	9.3	37.0
Medical schools	27.1	72.9	6.3	25.2	41.4
Psychology	47.2	52.8	5.9	5.1	41.8
Social sciences	47.1	52.9	6.0	9.3	37.6
Other sciences	63.6	36.4	4.2	7.6	24.6
Engineering	37.8	62.2	10.0	13.6	38.6

[a]Percent of current space.

NOTE: Data are based only on institutions reporting research space in a given field.

SOURCE: National Science Foundation, Division of Science Resources Statistics, *Scientific and Engineering Research Facilities: 2001,* NSF 02-307 (Arlington, VA, 2002).

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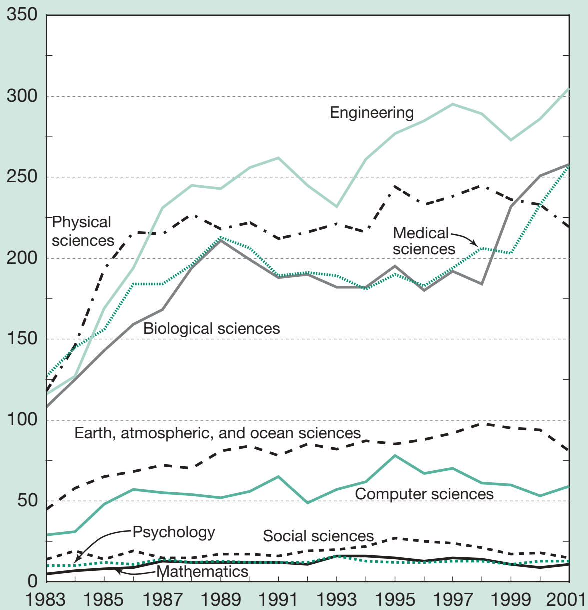
Figure 5-13
Current fund expenditures for research equipment at academic institutions, by field: 1983–2001

Millions of constant 1996 U.S. dollars



NOTE: See appendix table 4-1 for gross domestic product implicit price deflators used to convert current dollars to constant 1996 dollars.

SOURCES: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), *Academic Research and Development Expenditures: Fiscal Year 2001,* 2003; and NSF/SRS, WebCASPAR database system, http://caspar.nsf.gov. See appendix table 5-14.

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tion was lower in 2001 (4.6 percent) than it was in 1983 (5.7 percent), although it peaked in 1986 (7 percent) (appendix table 5-16). R&D equipment intensity varies across S&E fields. It tends to be higher in the physical sciences (about 9 percent in 2001) and lower in the social sciences (1.2 percent) and psychology (2.4 percent). For the two latter fields, these differences may reflect the use of less equipment, less expensive equipment, or both.

There has been recent congressional interest in this issue. Congress has asked NSF to reinstate the National Survey of Academic Research Instrumentation, last conducted in 1994, to determine the extent to which a lack of equipment and instrumentation prevents the academic research community from undertaking cutting-edge, world-class science.

Doctoral Scientists and Engineers in Academia

U.S. universities and colleges are major contributors to the nation's scientific and technological progress. They generate new knowledge and ideas that are vital to the advancement of science and form the basis of technological innovation. Concurrently, they also develop the highly trained talent needed to use and improve the knowledge base. In addition, academia increasingly plays an active role in the generation and use of new products, technologies, and processes.

The confluence of these key functions: the pursuit of new knowledge, the training of the people in whom it is embodied, and its exploitation toward generating innovation makes academia a national resource whose vitality rests in the scientists and engineers who work and study there. Especially important are those with doctoral degrees who do the research, teach and train the students, and stimulate or help to produce innovation.[18] Who are they, how are they distributed, what do they do, how are they supported, and what do they produce?

Employment and research activity at the 125 largest research-performing universities in the United States merit special attention.[19] These institutions exert a major influence on the nation's academic science, engineering, and R&D enterprise. They enroll 23 percent of full-time undergraduates and award 32 percent of all bachelor's degrees and 38 percent of those in S&E fields. These baccalaureate holders, in turn, are the source of 56 percent of the nation's S&E doctorate holders with a U.S. baccalaureate and more than 60 percent of those who are employed in academia and engaged in R&D as their primary work function. Moreover, these institutions conduct more than 80 percent of academic R&D (as measured by expenditures) and produce the bulk of both academic articles and patents. (See "Outputs of Scientific and Engineering Research: Articles and Patents" later in this chapter.)

Growth in academic employment over the past half century reflected both the need for teachers, driven by increasing enrollments, and an expanding research function, largely supported by Federal funds.[20] Because of the interrelationship between academic teaching and research, much of the discussion deals with the overall academic employment of S&E doctorate holders, specifically, the relative balance between faculty and nonfaculty positions, demographic composition, faculty age structure, hiring of new doctorate holders, trends in work responsibilities, and trends in Federal support. This section also discusses different estimates of the nation's academic R&D workforce and effort and considers whether a shift has been occurring away from basic research toward more applied R&D activities.

[18]*Innovation* is the generation of new or improved products, processes, and services. For more information, see chapter 6.

[19]This set of institutions comprises the Carnegie Research I and II universities, based on the 1994 classification. These institutions have a full range of baccalaureate programs, have a commitment to graduate education through the doctorate, award at least 50 doctoral degrees annually, and receive Federal support of at least $15.5 million (1989–91 average); see Carnegie Foundation for the Advancement of Teaching (1994). The other Carnegie categories include master's (comprehensive) universities and colleges; baccalaureate (liberal arts) colleges; 2-year community and junior colleges; and specialized schools such as engineering and technology, business and management, and medical and law schools. The classification has since been modified, but the older schema is more appropriate to the discussion presented here.

[20]Trends in S&E indicators relating to research funding are discussed in the first section of this chapter, "Financial Resources for Academic R&D."

The main findings are a relative shift in employment of S&E doctorate holders away from the academic sector toward other sectors; a slower increase in full-time faculty positions than in postdoc and other full- and part-time positions; a relative shift in hiring away from white males toward women and minorities; an aging academic doctoral labor force; a decline in the share of academic researchers who receive Federal support; and growth of an academic researcher pool outside the regular faculty ranks.

Trends in Academic Employment of Doctoral Scientists and Engineers

Academic employment of S&E doctorate holders reached a record high of 245,500 in 2001.[21] However, long-term growth in the number of these positions over the past quarter century was slower than in business, government, and other segments of the economy. Growth in the academic sector was also much slower in the 1990s than it was in the 1970s and 1980s (table 5-5). As a result, the share of all S&E doctorate holders employed in academia dropped from about 53 to 44 percent during the 1975–2001 period (table 5-6). Although the share of those with recently awarded degrees also declined between 1975 and 2001 (from 52 to 49 percent), in 2001 it was still larger than the overall academic employment share for S&E doctorate holders.[22] Within academia, growth in employment of S&E doctorate holders was slower at the major research universities than at other academic institutions. Appendix table 5-17 breaks down academic employment by type of institution.

Table 5-6
S&E doctorate holders employed in academia, by years since doctorate: Selected years, 1975–2001
(Percent)

Years since doctorate	1975	1981	1991	2001
Employed doctorate holders	53.4	49.7	44.7	44.0
3 or fewer	51.9	49.2	47.5	48.8
4–7	52.6	46.9	42.7	41.6
More than 7	54.3	50.6	44.7	43.9

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations.

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Table 5-5
Average annual growth rates for employment of S&E doctorate holders in U.S. economy: 1975–2001
(Percent)

Sector	1975–2001	1975–81	1981–91	1991–2001
All sectors	3.1	5.0	3.4	1.7
Academia	2.4	3.7	2.3	1.5
Research universities	1.9	3.6	2.1	0.7
All other	2.8	3.8	2.7	2.4
Business	4.2	7.5	2.2	4.2
Government	3.7	5.0	2.3	4.4
Other	3.3	5.1	8.7	–2.9

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations.

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Hiring at Research Universities and Public Institutions

Employment growth over the past decade was much slower at the research universities than at other academic institutions. From 1991 to 2001, doctoral S&E employment at research universities grew by less than 1 percent annually, whereas employment at other institutions increased by 2.4 percent annually. During the same period, employment increased less rapidly at public universities and colleges than at their private counterparts (0.9 versus 1.4). However, this pattern held only at research universities (0.4 versus 1.4) and not at other academic institutions (1.6 versus 1.4) (figure 5-14, table 5-5, and appendix table 5-18).

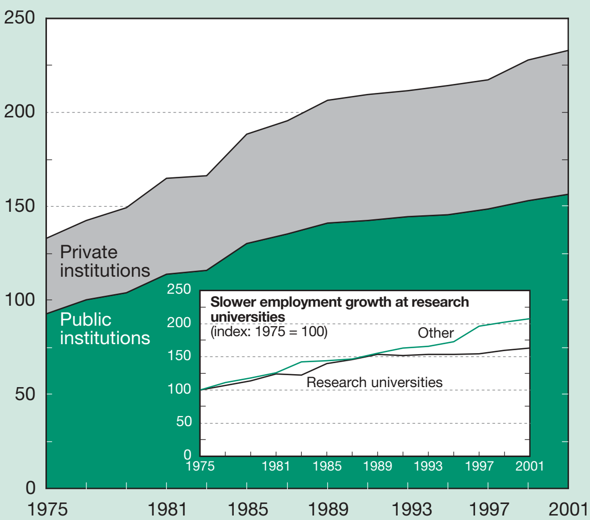
All Academic S&E Doctoral Employment

Trends in academic employment of S&E doctorate holders suggest movement away from the full-time faculty position as the academic norm. During the past quarter century, overall academic employment of S&E doctorate holders grew from 134,100 in 1975 to 245,500 in 2001 (appendix table 5-19). However, during this period, full-time faculty positions increased more slowly than postdoc and other full- and part-time positions. This trend accelerated during the past decade (table 5-7). Between 1991 and 2001, the number

[21] The academic doctoral S&E workforce includes those with a doctorate in an S&E field in the following positions: full and associate professors (referred to as senior faculty); assistant professors and instructors (referred to as junior faculty); postdocs; other full-time positions such as lecturers, adjunct faculty, research and teaching associates, and administrators; and part-time positions of all kinds. Unless specifically noted, data on S&E doctorate holders refer to persons with an S&E doctorate from a U.S. institution, as surveyed biennially by NSF in the Survey of Doctorate Recipients. All numbers are estimates rounded to the nearest 100. The reader is cautioned that small estimates may be unreliable.

[22] Recently awarded degrees are defined here as those earned at a U.S. university within 3 years of the survey year.

Figure 5-14
S&E doctorate holders employed in public and private universities and colleges: 1975–2001



SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations. See appendix table 5-18.

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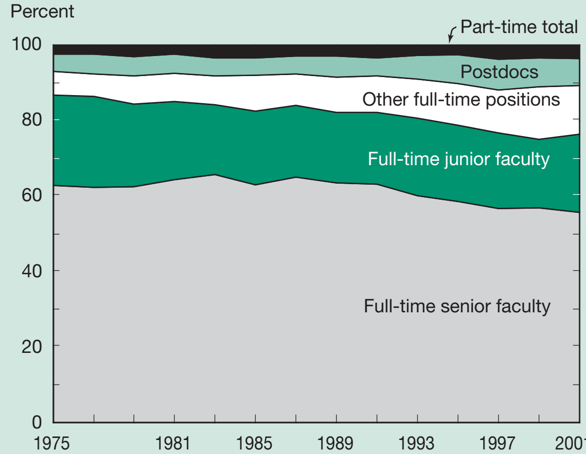
Figure 5-15
S&E doctorate holders, by type of academic appointment: 1975–2001



NOTE: Junior faculty includes assistant professors and instructors; senior faculty includes full and associate professors; other full-time positions include nonfaculty positions such as research associates, adjunct positions, lecturers, and administrative positions.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations. See appendix table 5-18.

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Table 5-7
Average annual growth rates for S&E doctorate holders, by academic position: 1975–2001
(Percent)

Academic position	1975–2001	1975–81	1981–91	1991–2001
All positions	2.4	3.7	2.3	1.5
Full-time faculty	1.8	3.4	2.0	0.8
Professors	2.2	5.1	2.5	0.3
Associate professors	1.4	2.8	1.6	0.3
Junior faculty[a]	1.8	1.3	1.5	2.3
Full-time nonfaculty[b]	5.3	7.2	4.8	4.6
Postdocs	4.1	5.4	1.5	5.8
Part-time	4.0	3.8	6.3	1.9

[a]Assistant professors or instructors.
[b]Positions such as research associates, adjunct positions, lecturers, and administrative positions.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations. See appendix table 5-18.

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of junior faculty rose only modestly (about 20 percent), while the number of senior faculty, full and associate professors, remained static. Meanwhile, full-time nonfaculty positions grew by half, as did postdoc positions.

Figure 5-15 shows the resulting distribution of academic employment of S&E doctorate holders. The share of full-time senior faculty fell from just over 63 percent of total employment in 1991 to less than 56 percent in 2001. The share of junior faculty fluctuated between 18 and 20 percent between 1983 and 1999, before increasing to just below 21 percent in 2001. The overall faculty share was 76 percent of all academic employment in 2001, down from 85 percent in the late 1970s. These employment trends in the past decade occurred as real spending for academic R&D rose by half, retirement of faculty who were hired during the expansionist 1960s increased, academic hiring of young doctorate holders showed a modest rebound, and universities displayed greater interest in the practical application of academic research results, discussed later in this chapter.[23]

Nonfaculty ranks, that is, full- and part-time adjunct faculty, lecturers, research and teaching associates, administrators, and

[23]It is impossible with the data at hand to establish causal connections among these developments.

postdocs, increased from 37,500 in 1991 to 58,200 in 2001. This 55 percent increase stood in sharp contrast to the 8 percent rise in the number of full-time faculty. Both the full-time nonfaculty and postdoc components grew rapidly between 1991 and 2001, while part-time employment rose more slowly.[24] Part-time employees accounted for only between 2 and 4 percent of all academic S&E doctoral employment throughout the period (appendix table 5-19).

Recent S&E Doctorate Holders

The trends just discussed reflect the entire academic workforce of S&E doctorate holders. Another picture of current trends can be found by looking at the academic employment patterns of those with recently awarded S&E Ph.D.s (degrees earned at U.S. universities within 3 years of the survey year).

Overall, recent doctorate holders who entered academic employment were about as likely to receive postdoc positions as faculty positions. Those in research universities, however, were more likely to be in postdoc than in faculty positions (appendix table 5-20 and figure 5-16). Since 1975, the share of recent doctorate holders hired into full-time faculty positions has been cut by more than one-third overall, from 70 to 44 percent. The decline in such employment at research universities has been relatively steeper, from 57 to 30 percent. Conversely, the overall share of recent S&E doctorate holders who reported being in postdoc positions has risen from 18 to 39 percent (and from 29 to 53 percent at research universities). However, after increasing steadily throughout the 1990s, the share of recent S&E doctorate holders in postdoc positions declined between 1999 and 2001 at both research universities and all other institutions. Whether or not this is the beginning of a trend remains to be seen.

Young Doctorate Holders With Track Records

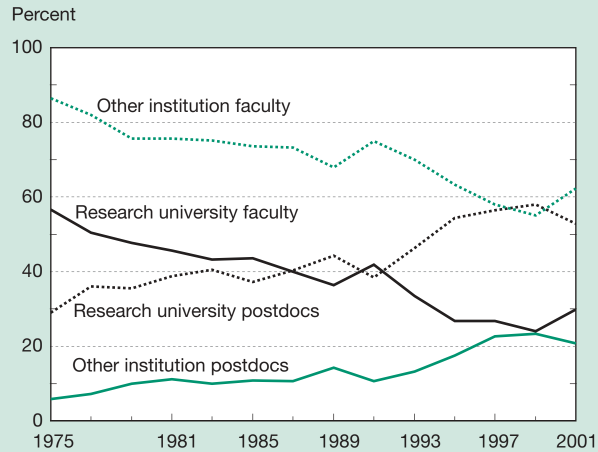
For those employed in academia 4–7 years after earning their doctorates, the picture looks quite similar: about 63 percent had faculty rank in 2001, compared with about 87 percent in the mid-1970s, with the trend continuing downward since 1991. About half were in tenure-track positions, with only 9 percent already tenured. The shares of both those in tenure-track positions and those with tenure have been declining since 1991, suggesting a continuing shift toward forms of employment outside traditional tenure-track positions (figure 5-17). Trends at research universities are similar. However, at the research universities, the share of those in faculty, tenured, or tenure-track positions is much smaller than at other academic institutions (appendix table 5-20).

Shift in Employment

The relative shift toward nonfaculty employment affected almost every major S&E degree field. Although the number of S&E full-time faculty positions increased from 173,100 to 187,400 between 1991 and 2001, two-thirds of this increase occurred in the life sciences, mostly among women. The only other fields in which full-time faculty positions increased by more than 10 percent over this 10-year period were the computer sciences and the earth, atmospheric, and ocean sciences. The share of all doctoral employment held by full-time faculty was lower in 2001 than in 1991 in every broad S&E field.

[24]For more information on this subject, see “Postdocs” in chapter 3.

Figure 5-16
S&E doctorate holders with recent degrees employed at research universities and other academic institutions, by type of position: 1975–2001



NOTES: Recent doctorate holders are those who earned their degrees within 3 years of the survey year. Faculty are employed full time as full, associate, and assistant professors and instructors.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations. See appendix table 5-20.

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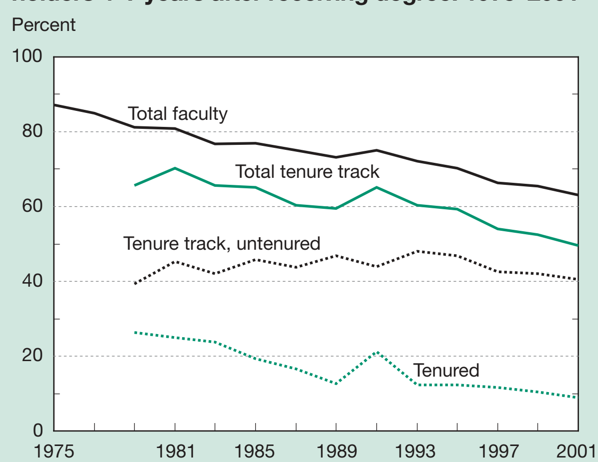
Figure 5-17
Faculty and tenure track status of S&E doctorate holders 4–7 years after receiving degree: 1975–2001



NOTES: Faculty positions include full, associate, and assistant professors and instructors. Tenure track data not available for 1975–77.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations. See appendix table 5-20.

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However, in many of these fields, the relative shift toward nonfaculty positions appears to have either slowed down or leveled off after 1995 (appendix table 5-19).

Retirement of S&E Doctoral Workforce

The trend toward fewer faculty and more full-time nonfaculty and postdoc positions is especially noteworthy because academia is approaching a period of increasing retirements. In the 1960s, the number of institutions, students, and faculty in the United States expanded rapidly, bringing many young Ph.D. holders into academic faculty positions. This growth boom slowed sharply in the 1970s, and faculty hiring has since continued at a more modest pace. The result is that increasing numbers of faculty (and others in nonfaculty positions) are today reaching or nearing retirement age.[25]

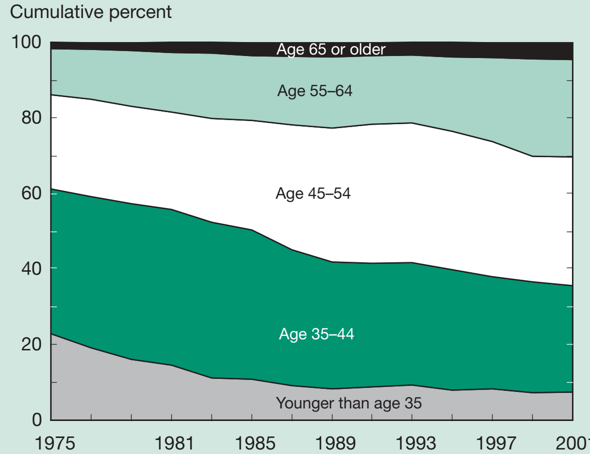
The Age Discrimination in Employment Act of 1967 became fully applicable to universities and colleges in 1994.[26] It prohibits the forced retirement of faculty at any age, raising concerns about the potential ramifications of an aging professorate for scholarly productivity and the universities' organizational vitality, institutional flexibility, and financial health. These concerns were the focus of a 1991 National Research Council (NRC) study that concluded that "overall, only a small number of the nation's tenured faculty will continue working in their current positions past age 70" (NRC 1991, p. 29), but added, "At some research universities a high proportion of faculty would choose to remain employed past age 70 if allowed to do so" (NRC 1991, p. 38).

Sufficient data have now accumulated to allow examination of some of these concerns. Figure 5-18 shows the age distribution of academic S&E doctorate holders in full-time faculty positions, and figure 5-19 displays the percentage that are 60 years of age or older. The data indicate that individuals age 65 or older (and 70 years or older) constitute a growing share of the S&E doctorate holders employed in academia, suggesting that the Age Discrimination in Employment Act may in fact have had some impact on the age distribution of the professoriate. The data also show that the share of 60- to 64-year-olds was rising well before the act became mandatory, leveled off in the early 1990s, and began to rise again after 1995, reaching just over 10 percent in 2001. A similar progression can be seen for those age 65 or older, who in 2001 made up just over 5 percent of the research universities' full-time faculty and slightly less than 4 percent of other institutions' full-time faculty. The employment share of those older than 70 also rose during most of the past quarter century, reaching about 1.1 percent of all S&E doctorate holders employed in academia in 2001 and 1.2 percent of full-time faculty in 1999 and remaining at that level in 2001 (appendix tables 5-21 and 5-22).

[25]See also the discussion of retirements from the S&E workforce in chapter 3, "Science and Engineering Labor Force."

[26]A 1986 amendment to the Age Discrimination in Employment Act of 1967 (Public Law 90-202) prohibited mandatory retirement on the basis of age for almost all workers. Higher education institutions were granted an exemption through 1993 that allowed termination of employees with unlimited tenure who had reached age 70.

Figure 5-18
Age distribution of academic S&E doctorate holders employed in faculty positions: 1975–2001



NOTE: Faculty are employed full time as full, associate, and assistant professors and instructors.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations. See appendix table 5-21.

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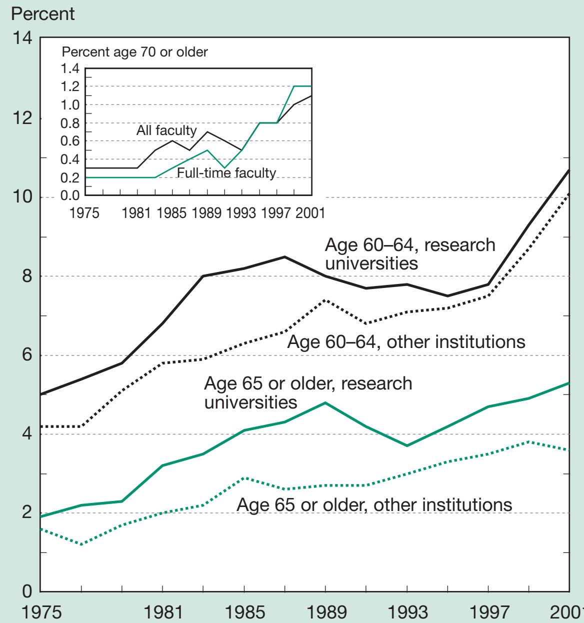
Figure 5-19
Full-time faculty age 60 and older at research universities and other higher education institutions: 1975–2001



NOTE: Faculty positions include full, associate, and assistant professors and instructors.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations. See appendix table 5-22.

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Table 5-8
Female and minority S&E doctorate holders employed in academia, by Carnegie institution type: Selected years, 1975–2001
(Percent)

Group and institution type[a]	1975	1981	1991	2001
Female				
Research universities	8.8	12.9	18.8	28.1
Other academic institutions	12.1	15.0	21.2	29.3
Underrepresented minority[b]				
Research universities	1.8	2.6	3.8	5.9
Other academic institutions	3.1	4.5	5.7	7.8
Asian/Pacific Islander				
Research universities	4.9	7.0	8.9	13.3
Other academic institutions	4.1	5.9	6.9	9.3

[a]As defined according to *A Classification of Institutions of Higher Education,* Carnegie Foundation for the Advancement of Teaching (Princeton, NJ, 1994).
[b]Blacks, Hispanics, and American Indian/Alaskan Natives.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations.

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Increasing Role of Women and Minority Groups

Women and underrepresented minority groups make up a pool of potential scientists and engineers that has not been fully tapped and that, in the case of underrepresented minorities, represents a growing share of U.S. youth, estimated to reach 36 percent of the college-age population by 2020 (appendix table 2-4). Accumulating research points to the importance of role models and mentoring to student success in mathematics, science, and engineering, especially for women and underrepresented minorities.[27] Thus, the presence of women and underrepresented minorities among faculty on college campuses is likely to be a factor in the recruitment of students from both groups to the S&E fields. What were the major hiring trends for them, and what is their current status?

Women

The academic employment of women with S&E doctorates has risen steeply over the past quarter century, reflecting the increase in the proportion of women among recent S&E doctorate holders. The number of women in academia increased more than fivefold between 1975 and 2001, from 13,800 to an estimated 70,500 (appendix table 5-23). This increase is reflected in the rising share of academic positions held by women with S&E doctorates. In 2001, women constituted 29 percent of all academic S&E doctoral employment and just over one-fourth of full-time faculty, up from 10 and 9 percent, respectively, in 1975. Although women made up a smaller share of total employment at research universities than at other academic institutions at the beginning of this period, this differential had almost disappeared by the end of the period (table 5-8). Compared with male faculty, female faculty remain relatively more heavily concentrated in life sciences and psychology, with correspondingly lower shares in engineering, physical sciences, and mathematics.

Women's growing share of academic employment may reflect the confluence of three factors: their rising proportion among new doctorate holders, their somewhat greater predilection for choosing employment in an academic setting than men, and being hired into these positions at somewhat higher rates than men. This historical dynamic is reflected in declining absolute numbers of women and a declining relative share of women as faculty rank increases. In 2001, women constituted 16 percent of full professors, 29 percent of associate professors, and 39 percent of junior faculty, the latter roughly in line with their share of recently earned S&E doctorates.[28] In contrast, both the number and relative share of men increases absolutely from the junior to the senior faculty ranks (See appendix table 5-23 and figure 5-20. For a discussion of some additional factors that may explain these differences, see sidebar "Gender Differences in the Academic Careers of Scientists and Engineers.") This contrasting pattern indicates the recent arrival of significant numbers of female doctorate holders in full-time academic faculty positions. It suggests that the number of women among the faculty will continue to increase, assuming that they stay in academic positions at a rate equal to or greater than that of men.

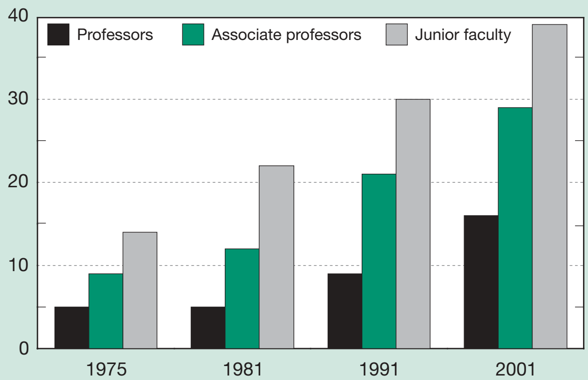
Underrepresented Minority Groups

The U.S. Census Bureau's demographic projections have long indicated an increasing prominence of minority groups among future college- and working-age populations. With the exception of Asian/Pacific Islanders, these groups tended to be less likely than whites to earn S&E degrees or work

[27]For more information about the effects of mentoring, see *Diversity Works: The Emerging Picture of How Students Benefit,* by Daryl G. Smith and Associates (Washington, DC: Association of American Colleges and Universities, 1997).

[28]See "Doctoral Degrees by Sex" in chapter 2.

Figure 5-20
Female doctoral S&E faculty positions, by rank: Selected years, 1975–2001



NOTE: Junior faculty includes assistant professors and instructors.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations.

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in S&E occupations.[29] Private and governmental groups sought to broaden the participation of blacks, Hispanics, and American Indian/Alaskan Natives in these fields, with many programs targeting their advanced training through the doctorate.

In response, the absolute rate of conferral of S&E doctorates to members of underrepresented minority groups has increased, as has academic employment; but taken together, blacks, Hispanics, and American Indian/Alaskan Natives remain a small percentage of the S&E doctorate holders employed in academia (appendix table 5-24). Because the increases in hiring come from a very small base, these groups still constituted less than 7 percent of both total academic employment and full-time faculty positions in 2001, up from just above 2 percent in 1975. Underrepresented minorities constituted a smaller share of total employment at research universities than at other academic institutions throughout this period (table 5-8). However, among recent Ph.D. holders, they represented almost 9 percent of total academic employment and nearly 10 percent of full-time faculty positions. These trends are similar for all underrepresented minorities and for those who are U.S. citizens (figure 5-21). Compared with whites, blacks tended to be relatively concentrated in the social sciences and psychology and relatively less represented in the physical sciences; the earth, atmospheric, and ocean sciences; mathematics; and the life sciences. The field distribution of Hispanic degree holders is similar to that of white degree holders.

[29]See chapter 2, "S&E Bachelor's Degrees by Race/Ethnicity," "Master's Degrees by Race/Ethnicity," and "Doctoral Degrees by Race/Ethnicity."

Gender Differences in the Academic Careers of Scientists and Engineers

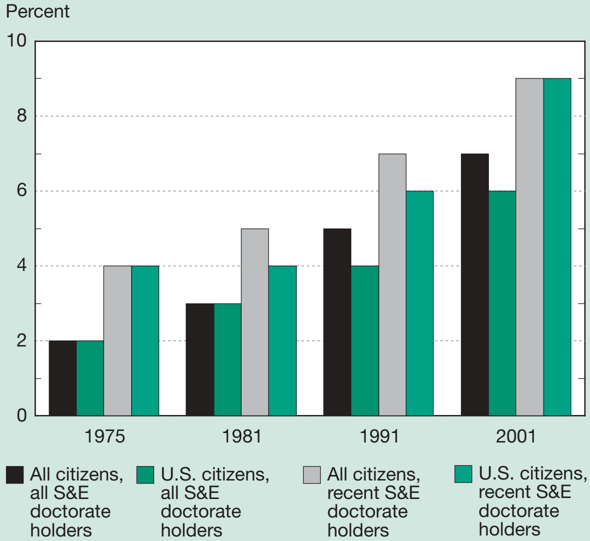
A recent study supported by the National Science Foundation's Division of Science Resources Statistics (NSF/SRS forthcoming) used data from the NSF biennial Survey of Doctorate Recipients to examine gender differences for four outcomes that reflect successful movement along the academic career path: tenure-track placements, earning tenure, promotion to the rank of associate professor, and promotion to the rank of full professor.

Women scientists and engineers appear to lag behind their male counterparts in moving along the academic career path. A part of these gender differences seems to be related to gender differences in the influence of certain family characteristics. Married women and women with children were less successful than married men with children. That is, married women with children had reduced opportunities, relative to their male counterparts, to be employed in tenure-track positions and to earn tenure. This finding holds for any given time in their careers. Women employed full-time in academia with 14–15 or 20–21 years of postdoctoral experience were more likely than men to be employed in junior ranks and less likely to be full professors.

The study employed multivariate techniques that permitted the statistical control of a large number of factors in addition to gender that might be related to career outcomes. These included measures of human capital, personal and family characteristics, and time of earning the doctorate. A set of models that included female interaction variables as controls was also estimated. These models, which allowed for gender differences in the influence of family characteristics on career outcomes, enabled the testing of hypotheses about whether being married and having children affect the careers of women and men differently. The study was careful to measure family characteristics at common points in individuals' postdoctoral careers because of the suspicion that the timing of decisions about marital status and fertility are important.

The study was conducted in two phases. Phase I looked at gender differences in the likelihood that doctorate holders will successfully achieve outcomes at specific points in time along the academic career path. Phase II, longitudinal in nature, considered gender differences in the amount of time doctorate holders take to achieve career milestones. For the most part, both phases came up with similar results.

Figure 5-21
Underrepresented minority S&E doctorate holders employed in academia, by citizenship status and time since degree: Selected years, 1975–2001



NOTES: The numerator and denominator always refer to the set of individuals defined in the legend, the numerator being underrepresented minorities and the denominator being the entire set. Underrepresented minorities include blacks, Hispanics, and American Indian/Alaskan Natives. Recent doctorate holders are those who earned their degrees within 3 years of the survey.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations.

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Asian/Pacific Islanders

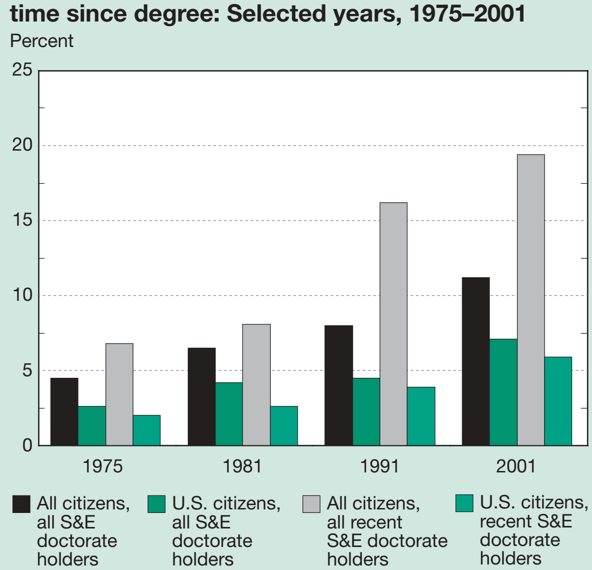
Asian/Pacific Islanders were successful in entering the academic doctoral workforce in S&E, more than doubling in employment share from 5 to 11 percent between 1975 and 2001 (appendix table 5-24). However, a distinction needs to be made between those who are U.S. citizens and those who are not, because the latter group constituted more than 40 percent of this group's doctorate holders in the academic S&E workforce in 2001.[30] The employment share of Asian/Pacific Islanders who are U.S. citizens grew from less than 3 percent of the academic S&E doctoral workforce in 1973 to about 7 percent in 2001. Asian/Pacific Islanders, whether or not they are U.S. citizens, represent a larger percentage of total employment at research universities than at other academic institutions (table 5-8). Limiting the analysis to recent S&E doctorate holders leads to even more dramatic differences between Asian/Pacific Islanders who are U.S. citizens and those who are not. Whereas the share of all recent Asian/Pacific Islander S&E doctorate holders employed in academia rose from just below 7 percent in 1975 to more than 19 percent in 2001, the share of those who are U.S. citizens increased from 2 percent to slightly less than 6 percent (figure 5-22). Although the current employment shares of Asian/Pacific Islanders who are U.S. citizens are almost identical to those of underrepresented minorities, the former group is overrepresented relative to its share of the U.S. population, while the latter is underrepresented.

Compared with whites, Asian/Pacific Islanders as a whole are more heavily represented in engineering and computer sciences and represented at very low levels in psychology and social sciences. This finding holds both for U.S. citizens and for all Asian/Pacific Islanders. In 2001, Asian/Pacific Islanders constituted nearly one-fourth of academic doctoral computer scientists and 18 percent of engineers (appendix table 5-24).

Whites

The role of whites, particularly white males, in the academic S&E doctoral workforce diminished between 1975 and 2001. In 2001, whites constituted 82 percent of the academic doctoral S&E workforce, compared with 91 percent in 1975 (appendix table 5-24). The share of white males declined from about 81 percent to about 59 percent during this period (table 5-9). The decline in the shares of whites and white males who recently received their doctorates was even greater—from 87 to 72 percent and from 73 to 41 percent, respectively (table 5-9). Part of the decline is because of the increasing roles played by women, underrepresented minori-

Figure 5-22
Asian/Pacific Islander S&E doctorate holders employed in academia, by citizenship status and time since degree: Selected years, 1975–2001



NOTES: The numerator and denominator always refer to the set of individuals defined in the legend, the numerator being Asian/Pacific Islanders and the denominator being the entire set. Recent doctorate holders are those who earned their degrees within 3 years of the survey.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations.

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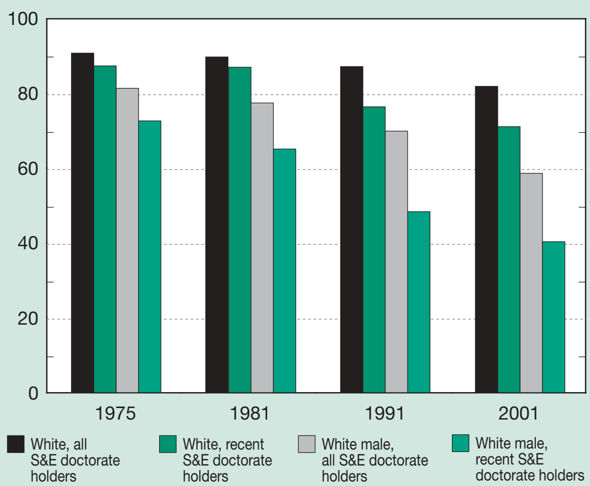
[30]Both the number and share of Asian/Pacific Islander S&E doctorate recipients employed in academia are probably larger than is reported here because those who received S&E Ph.D.s from universities outside the United States are not included in the analysis.

ties, and Asian/Pacific Islanders. However, the decline in the share of white males was exacerbated by a fall in the absolute number of white males in the academic doctoral S&E workforce during the 1990s (figure 5-23).

Foreign-Born S&E Doctorate Holders

An increasing number and share (more than 20 percent) of S&E doctorate holders employed at U.S. universities and colleges are foreign born. Like other sectors of the economy, academia has long relied extensively on foreign talent among its faculty, students, and other professional employees. This reliance increased fairly steadily during the 1980s and 1990s. Figure 5-24 delineates the academic employment estimate of 245,500 U.S.-earned S&E doctorates into those awarded to native-born and foreign-born individuals.[31] However, in addition to foreign-born individuals who hold S&E doctorates from U.S. institutions, U.S. universities and colleges also employ a substantial number of foreign-born holders of S&E doctorates awarded by foreign universities. In *Science & Engineering Indicators – 2002*, a lower value of about 25,000 was estimated for the latter group, which would increase the share of foreign-born Ph.D.-level scientists and engineers employed at U.S. universities and

Figure 5-23
White and white male S&E doctorate holders employed in academia, by time since degree: Selected years, 1975–2001



NOTE: Recent doctorate holders are those who earned their degrees within 3 years of the survey.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations.

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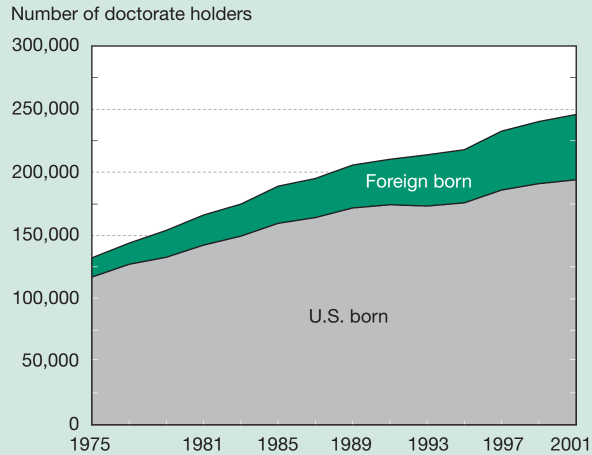
Figure 5-24
Academic employment of U.S. S&E doctorate holders, by place of birth: 1975–2001



SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations. See appendix table 5-25.

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Table 5-9
White and white male S&E doctorate holders employed in academia, by years since degree: Selected years, 1975–2001

	1975		1981		1991		2001	
Group	Thousands	Percent	Thousands	Percent	Thousands	Percent	Thousands	Percent
All S&E doctorate holders	134.1	100	167.1	100	210.6	100	245.5	100
White	121.6	91	149.9	90	183.5	87	201.0	82
White male	109.0	81	129.3	77	147.1	70	144.0	59
Recent S&E doctorate holders	23.4	100	20.7	100	25.5	100	28.3	100
White	20.4	87	18.0	87	19.5	77	20.2	72
White male	17.0	73	13.5	65	12.3	48	11.5	41

NOTE: Recent doctorate holders are those who earned their degrees within 3 years of the survey year.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations.

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[31] In 2001, 57 percent of those who were foreign born were U.S. citizens.

colleges to closer to 30 percent. Because there are no current data on which to base a solid estimate of the number of foreign-born doctorate holders in the United States, and because the available information on the faculty status of holders of doctorates awarded by foreign universities and on which academic institutions employ them is insufficient to draw reliable conclusions, all discussion is based on holders of U.S. doctorates only.

Participation in higher education by foreign-born individuals with U.S.-earned S&E doctoral degrees has increased continuously, both in number and share, since the late 1970s. Academic employment of foreign-born S&E doctorate holders rose from an average of about 12 percent of the total in 1975 to 21 percent in 2001, with some fields reaching considerably higher proportions; for postdocs, the average is almost double that percentage (41 percent) (appendix table 5-25).[32]

Size of Academic Research Workforce

The interconnectedness of research, teaching, and public service in academia makes it difficult to measure the size of the academic research workforce precisely.[33] Therefore, two estimates of the number of academic researchers are presented: a count of those who report that research is their primary work activity, and a count of those who report that research is either their primary or secondary work activity.[34]

Postdocs and those in nonfaculty positions are included in both estimates.[35] To provide a more complete measure of the number of individuals involved in research at academic institutions, a lower-bound estimate of the number of full-time graduate students who support the academic research enterprise is included, based on those whose primary mechanism of support is a research assistantship (RA). This estimate excludes graduate students who rely on fellowships, traineeships, or teaching assistantships for their primary means of support, as well as the nearly 40 percent who are primarily self-supporting. Many, if not most, of these students are also likely to be involved in research activities during the course of their graduate education.[36]

Research as Primary Work Activity

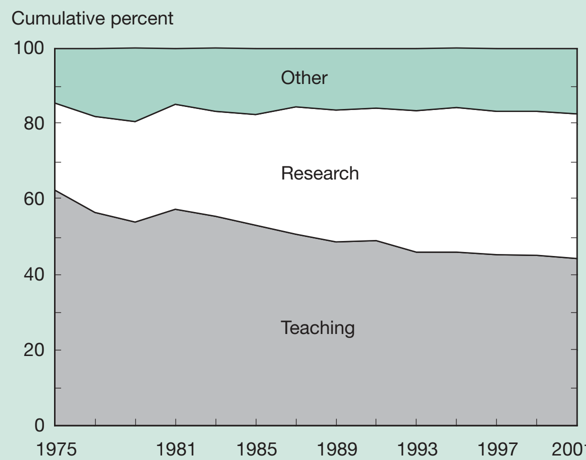
By this measure, the growth of academic researchers with S&E doctorates has been substantial, from 30,800 in 1975 to 93,800 in 2001 (appendix table 5-26). During this period, the number of those with teaching as their primary activity increased much less rapidly, from 83,800 to 109,000. Figure 5-25 displays the resulting shifting proportions in the academic workforce. However, after many years of increase, the proportion of those reporting research as their primary activity leveled off in the 1990s, as did the steep drop in those reporting teaching as their primary activity.

The different disciplines have distinct patterns of relative emphasis on research, but the shapes of the overall trends are roughly the same. The life sciences stand out, with a much higher share identifying research as their primary activity and, correspondingly, a much lower share reporting teaching as their primary activity. Conversely, mathematics and the social sciences have the largest shares identifying teaching as their primary activity and the lowest shares reporting research as their primary activity (figure 5-26).

Research as Either Primary or Secondary Work Activity

The count of academic S&E doctorate holders reporting research as their primary or secondary work activity also shows greater growth in the research than in the teaching component. The number of doctoral researchers in this group increased from 90,600 in 1975 to 172,500 in 2001, whereas teachers increased from 110,400 to 160,600 (appendix table 5-27).[37]

Figure 5-25
Primary work activity of S&E doctorate holders employed in academia: 1975–2001



NOTE: Research includes basic or applied research, development, or design.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations. See appendix table 5-26.

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[32]For a more thorough discussion of the role of foreign scientists and engineers, see chapter 2, "Higher Education in Science and Engineering," and chapter 3, "Science and Engineering Labor Force."

[33]Public service includes activities established primarily to provide noninstructional services beneficial to individuals and groups external to the institution. These activities include community service programs and cooperative extension services.

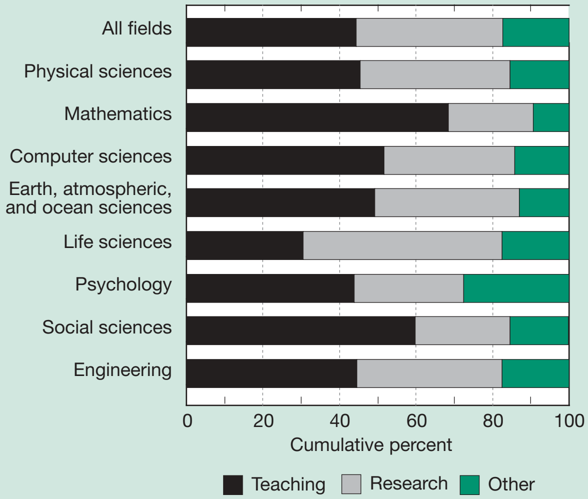
[34]The academic research function encompasses four separate items: basic research, applied research, development, and design. In the following discussion, unless specifically stated otherwise, the term *research* refers to all four.

[35]For technical reasons, the postdoc number excludes holders of S&E doctorates awarded by foreign universities. Data from NSF's Survey of Graduate Students and Postdoctorates in Science and Engineering suggest that in 2001 the number of postdocs with doctorates from foreign institutions was approximately twice that of those with U.S. doctorates. Most of them could be expected to have research as their primary work activity.

[36]For a more detailed treatment of graduate education in general, including the mix of graduate support mechanisms and sources, see chapter 2, "Higher Education in Science and Engineering."

[37]This measure was constructed slightly differently in the 1980s and in the 1990s, starting in 1993, and is not strictly comparable across these periods. Therefore, the crossing over of the two trends in the 1990s could reflect only a methodological difference. However, the very robust trend in the life sciences, where researchers started outnumbering teachers much earlier, suggests that this methodological artifact cannot fully explain the observed trend.

Figure 5-26
Primary work activity of academic S&E doctorate holders employed in academia, by degree field: 2001



NOTE: Research includes basic or applied research, development, or design.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations. See appendix table 5-26.

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The life sciences accounted for much of this trend, with researchers growing from 29,000 to 63,100 and teachers from about the same base of 29,600 to 44,400. The other fields generally included fewer researchers than teachers in the 1970s and early 1980s, but this trend has been reversed for the physical sciences; the earth, atmospheric, and ocean sciences; and engineering.

Graduate Research Assistants

The close coupling of advanced training with hands-on research experience is a key strength of U.S. graduate education. To the count of S&E doctoral researchers for whom research is a primary or secondary work activity can be added an estimate of the number of S&E graduate students who are active in research. The more than 350,000 full-time S&E graduate students (as of 2001) can be expected to contribute significantly to the conduct of academic research.

Graduate RAs were the primary means of support for slightly more than one-fourth of these students. Table 5-10, which shows the distribution of all full-time S&E graduate students and graduate research assistants by field over the past quarter century, indicates that the number of research assistants has grown considerably faster than graduate enrollment, both overall and in most fields. In both graduate enrollment and the distribution of RAs, there was a shift away from the physical sciences and social sciences and into the life sciences, computer sciences, and engineering. In engineering,

Table 5-10
Full-time S&E graduate students and graduate research assistants at U.S. universities and colleges, by degree field: Selected years, 1975–2001

	1975		1981		1991		2001	
Group and degree field	Thousands	Percent	Thousands	Percent	Thousands	Percent	Thousands	Percent
Graduate students	219.6	100	257.3	100	329.3	100	355.1	100
Physical sciences	21.9	10	26.7	10	28.9	9	27.1	8
Mathematics	10.7	5	11.8	5	13.4	4	12.5	4
Computer sciences	4.5	2	13.9	5	16.5	5	30.1	8
Earth, atmospheric, and ocean sciences	9.6	4	11.3	4	11.3	3	10.5	3
Life sciences	63.1	29	69.5	27	100.0	30	108.2	30
Psychology	24.1	11	25.3	10	35.2	11	34.5	10
Social sciences	48.0	22	42.8	17	56.2	17	54.6	15
Engineering	37.8	17	55.9	22	67.8	21	77.6	22
Graduate research assistants[a]	40.0	100	61.0	100	89.9	100	99.7	100
Physical sciences	6.4	16	10.3	17	11.8	13	11.8	12
Mathematics	0.6	2	1.0	2	1.5	2	1.4	1
Computer sciences	0.7	2	2.1	3	3.9	4	4.2	4
Earth, atmospheric, and ocean sciences	2.8	7	3.7	6	4.7	5	6.5	6
Life sciences	11.3	28	17.9	29	29.3	33	31.0	31
Psychology	2.2	6	3.1	5	4.6	5	4.9	5
Social sciences	4.8	12	5.1	8	7.2	8	7.8	8
Engineering	11.0	28	17.9	29	27.0	30	32.2	32

[a]Graduate students with primary research assistantship support.

NOTE: Details may not add to totals and percents may not sum to 100 because of rounding.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Graduate Students and Postdoctorates in Science and Engineering.

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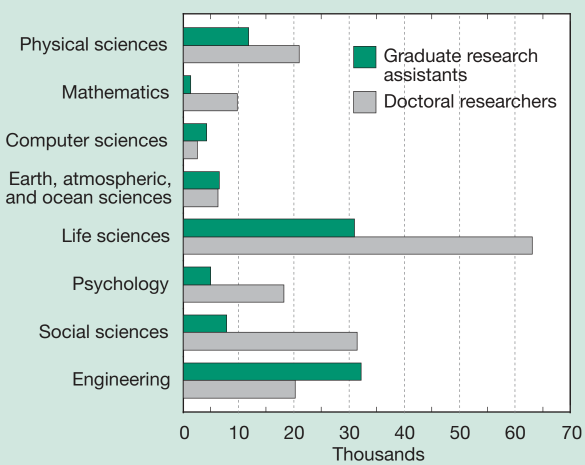
the physical sciences, and the earth, atmospheric, and ocean sciences the proportion of RAs is relatively high in relation to graduate enrollment. In the life sciences, the proportion of RAs relative to enrollment is more balanced, possibly reflecting the heavier reliance of these fields on postdoctoral researchers.

Adding graduate research assistants (full-time graduate students whose primary mechanism of support is an RA) to the count of S&E doctoral researchers for whom research is either the primary or secondary activity yields a more complete lower-bound measure of the number of individuals involved in academic research. With the caveats introduced earlier, the number of academic researchers in 2001 estimated in this way is approximately 272,000 (figure 5-27 and appendix table 5-28). It is worth noting that in both computer sciences and engineering, the number of graduate research assistants exceeded the number of doctoral researchers.

Deployment of Academic Research Workforce

This section discusses the distribution of the academic research workforce across types of institutions, positions, and fields. It also examines differences in research intensity by looking at S&E doctorate holders involved in research activities relative to all S&E doctorate holders employed in academia.

Figure 5-27
Estimated number of graduate research assistants and doctoral researchers in academia, by degree field: 2001



NOTES: Doctoral researchers include those whose primary or secondary work activity is basic or applied research, development, or design. Graduate research assistants are full-time graduate students with primary research assistantship support.

SOURCES: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), Survey of Doctorate Recipients, special tabulations; and NSF/SRS, Survey of Graduate Students and Postdoctorates in Science and Engineering. See appendix table 5-28.

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Distribution Across Types of Academic Institutions

The majority of the research workforce is concentrated in the research universities (appendix table 5-29). In 2001, the research universities employed 49 percent of S&E doctorate holders in academic positions, 57 percent of S&E doctorate holders reporting research as their primary or secondary activity, 71 percent of S&E doctorate holders whose primary activity was research, and 80 percent of S&E graduate research assistants.

Over the years, however, the research universities' share of S&E doctorate holders reporting research as their primary or secondary activity has declined, possibly reflecting these universities' decreasing shares of total and Federal expenditures for academic research. The research universities' losses were offset by gains in several other types of institutions.[38] Table 5-11 provides a long-term overview of the changes in these institutional distributions.

Distribution Across Academic Positions

A pool of academic researchers outside the regular faculty ranks has grown over the years, as shown by the distribution of S&E doctorate holders reporting research as their primary or secondary activity across different types of academic positions: faculty, postdoctoral fellows, and all other types of appointments (table 5-12 and appendix table 5-30). The faculty share declined from about 87 percent in 1975 to about 77 percent in 2001 (approximately the same as the change in overall employment share). The decline in faculty share was balanced by increases in the shares for both postdocs and those in other nonfaculty positions. However, the distribution across different types of academic positions for those reporting research as their primary activity changed little during this period.

Distribution Across S&E Fields

The distributions of total academic S&E doctoral employment and S&E doctoral academic research personnel (using various measures) across broad fields are not identical. Comparison of these distributions provides one possible measure of relative research intensity across fields. Researcher proportions in excess of a field's employment share could be deemed to indicate greater research intensity. Table 5-13 suggests that by these measures, research intensity is greater in the life sciences than in the other fields and relatively less in mathematics, psychology, and the social sciences (appendix table 5-31).

Research Intensity of Academic Institutions

A measure of research intensity similar to the one used above can be used to examine the change in research intensity in academia over time. In this case, the change in the relative importance given to R&D in U.S. universities

[38]For a more detailed discussion of these shifts, see *Changes in Federal Support for Academic S&E and R&D Activities Since the 1970s* (NSF/SRS forthcoming).

Table 5-11
S&E doctorate holders and graduate research assistants employed in academia, by Carnegie institution type: 1975–2001
(Percent distribution)

Group and institution type	1975–81	1981–91	1991–2001
All employed S&E doctorate-holders	100.0	100.0	100.0
Research universities	54.2	53.6	50.6
Doctorate-granting institutions	11.5	11.3	11.2
Comprehensive institutions	18.1	18.5	18.4
All others	16.3	16.6	19.8
Researchers[a]	100.0	100.0	100.0
Research universities	65.4	63.0	58.3
Doctorate-granting institutions	10.8	11.0	11.5
Comprehensive institutions	12.3	13.6	14.7
All others	11.5	12.5	15.6
Graduate research assistants[b]	100.0	100.0	100.0
Research universities	87.5	84.6	80.9
Doctorate-granting institutions	9.2	9.9	11.4
Comprehensive institutions	2.1	3.3	4.8
All others	1.2	2.2	2.8

[a]Research is primary or secondary work activity.
[b]Graduate students with primary research assistantship support.

NOTES: Institutional designation is according to *A Classification of Institutions of Higher Education,* Carnegie Foundation for the Advancement of Teaching (Princeton, NJ, 1994). Freestanding schools of engineering and technology are included under comprehensive institutions. “All others” includes freestanding medical schools, 4-year colleges, specialized institutions, and institutions without a Carnegie code. Percents may not sum to 100 because of rounding.

SOURCES: National Science Foundation, Division of Science Resources Statistics (NSF/SRS), Survey of Doctorate Recipients, special tabulations; and NSF/SRS, Survey of Graduate Students and Postdoctorates in Science and Engineering. See appendix table 5-29.

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Table 5-12
S&E doctorate holders employed in academia, by involvement in research and position: Selected years, 1975–2001

Involvement in research and position	1975	1985	1995	2001
	Thousands			
All academic employment	134.1	190.2	217.5	245.5
Research as primary or secondary activity	90.6	115.2	153.5	172.5
Research as primary activity	30.8	55.9	83.0	93.8
	Percent distribution			
All academic employment	100.0	100.0	100.0	100.0
Full-time faculty	86.8	82.5	78.8	76.3
Postdocs	4.6	4.6	7.7	7.1
Other full- and part-time positions	8.6	12.9	13.5	16.6
Research as primary or secondary activity	100.0	100.0	100.0	100.0
Full-time faculty	87.1	82.6	79.3	77.3
Postdocs	6.5	6.8	10.5	9.6
Other full- and part-time positions	6.4	10.6	10.2	13.1
Research as primary activity	100.0	100.0	100.0	100.0
Full-time faculty	69.5	70.7	68.2	67.0
Postdocs	18.5	13.4	18.2	16.6
Other full- and part-time positions	12.3	15.9	13.7	16.4

NOTES: Full-time faculty includes full, associate, and assistant professors plus instructors. Other full- and part-time positions include full-time nonfaculty such as research associates, adjunct positions, lecturers, administrative positions, and part-time positions of all kinds. Percents may not sum to 100 because of rounding.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations. See appendix table 5-30.

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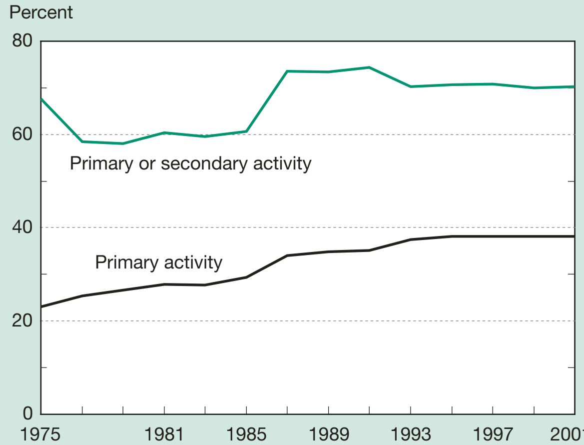
and colleges is addressed in terms of the number of S&E doctoral research personnel relative to all S&E doctoral employment in academia. Two measures of S&E doctoral personnel are used: the number reporting research as their primary or secondary work activity and the number reporting research as their primary work activity. These measures tell somewhat different stories, and the reader is cautioned that they are suggestive rather than definitive.

The number of S&E doctorate holders reporting research as primary or secondary activity relative to all S&E doctoral employment declined between 1975 and 1977; was relatively constant at about 60 percent from the mid-1970s to the mid-1980s, when R&D funds grew relatively slowly; then rose again in 1987 to about 74 percent; dropped to about 70 percent in 1993; and has remained relatively constant at that level since then (figure 5-28). On the other hand, the share of S&E doctorate holders in academia who reported research as their primary activity experienced a long-term upward trend from the mid-1970s through the mid-1990s, increasing from about 23 percent of total employment to about 38 percent, where it has remained since 1995. The latter trend is similar for each of the broad S&E fields except for the computer sciences, which is a new field relative to the others (table 5-14). These trends may indicate an overall strengthening of the research function in academia, at least through the mid-1990s.

Figure 5-28
S&E doctorate holders employed in academia, by involvement in research: 1975–2001



NOTE: Percent refers to S&E doctorate holders involved in research as percentage of all S&E doctorate holders.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations. See appendix table 5-30.

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Government Support of Academic Doctoral Researchers

Academic researchers rely on the Federal Government for a significant share, about 60 percent, of their overall research support. The institutional and field distributions of these funds are well documented, but little is known about their distribution across researchers. This section presents data from reports by S&E doctorate holders in academia about the presence or absence of Federal support for their work. However, nothing is known about the magnitude of these funds to individual researchers. (See sidebar, “Interpreting Federal Support Data.”)

Appendix table 5-32 shows the percentage of academic S&E doctorate holders who received Federal support for their work, broken out by field. The analysis examines the overall pool of doctoral S&E researchers as well as young doctorate holders, for whom support may be especially critical in establishing a productive research career.

Table 5-13
S&E doctorate holders employed in academia, by degree field and involvement in research: 2001
(Percent distribution)

Degree field	All academic employment	Involvement in research: Primary or secondary activity	Involvement in research: Primary activity
All fields	100.0	100.0	100.0
Physical sciences	12.4	12.2	12.7
Mathematics	6.1	5.7	3.5
Computer sciences	1.5	1.5	1.4
Earth, atmospheric, and ocean sciences	3.3	3.6	3.3
Life sciences	34.3	36.6	46.6
Psychology	12.4	10.5	9.3
Social sciences	19.1	18.2	12.4
Engineering	10.8	11.7	10.7

NOTE: Percents may not sum to 100 because of rounding.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations. See appendix table 5-31.

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Table 5-14
S&E doctorate holders employed in academia who reported research as primary activity, by degree field: Selected years, 1975–2001
(Percent)

Degree field	1975	1985	1995	2001
All fields	23.0	29.4	38.2	38.2
Physical sciences	27.1	34.8	42.9	39.1
Mathematics	13.6	19.9	22.6	22.1
Computer sciences	na	50.0	32.3	34.5
Earth, atmospheric, and ocean sciences	20.5	30.8	40.6	37.7
Life sciences	36.8	46.2	52.7	51.9
Psychology	14.9	19.9	28.4	28.6
Social sciences	11.4	13.6	23.1	24.9
Engineering	17.2	22.1	36.6	37.9

na not applicable

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations. See appendix table 5-31.

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Academic Scientists and Engineers Who Receive Federal Support

In 2001, the Federal Government provided support to an estimated 45 percent of all S&E doctorate holders in academia, about 74 percent of those for whom research was the primary activity, and about 36 percent of those for whom research was a secondary activity (appendix table 5-32). With the exceptions of engineering and the earth, atmospheric, and ocean sciences, no major shifts appear to have occurred in the overall percentage of those so supported during the 1993–97 period. However, as table 5-15 shows, the 2001 percentages for S&E as a whole and for each of the fields were below those for 1991.

The percentage of S&E doctorate holders in academia who received Federal support differed greatly across the S&E fields. In 2001, this percentage ranged from about 64 percent in the earth, atmospheric, and ocean sciences to about 22 percent in the social sciences (table 5-15 and appendix table 5-32).

Full-time faculty received Federal funding less frequently than other full-time doctoral employees, who, in turn, were supported less frequently than postdocs. In 2001, about 43 percent of full-time faculty, 49 percent of other full-time employees, and 74 percent of postdocs received Federal support. These proportions were lower than those during the latter part of the 1980s, but dropped less for full-time faculty than for postdocs or other full-time positions (appendix table 5-32). It is unclear whether these estimates indicate relatively less generous support or greater availability of funds from other sources, some of which may not flow through university accounts.

Interpreting Federal Support Data

Interpretation of the data on Federal support of academic researchers is complicated by a technical difficulty. Between 1993 and 1997, respondents to the Survey of Doctorate Recipients were asked whether work performed during the week of April 15 was supported by the Federal Government; in most other survey years, the reference was to the entire preceding year; in 1985, it was to 1 month. However, as these data series clearly illustrate, the volume of academic research activity is not uniform over the entire academic year. A 1-week (or 1-month) reference period seriously understates the number of researchers supported over an entire year. Thus, the numbers for 1985 and 1993–97 cannot be compared directly with results for the earlier years or those from the 1999 and 2001 surveys, which again used an entire reference year.

The discussion here compares data for 1999 and 2001 with the earlier series and examines trend information for the mid-1990s using the 1993–97 data points. All calculations express the proportion of those with Federal support relative to the number responding to this question. The reader is cautioned that, given the nature of these data, the trends discussed are broadly suggestive rather than definitive. The reader also is reminded that the trends in the proportion of all academic researchers supported by Federal funds occurred against a background of rising overall numbers of academic researchers.

Federal Support of Young S&E Doctorate Holders in Academia

Early receipt of Federal support is viewed as critical to launching a promising academic research career. The Federal Government supports young S&E doctorate holders in academia at slightly higher rates than it does the overall academic doctoral S&E workforce. However, the pattern of support for young researchers is similar to that of the overall academic S&E doctoral workforce: those in full-time faculty

Table 5-15
S&E doctorate holders employed in academia who received Federal support, by degree field: 1981, 1991, and 2001
(Percent)

Degree field	1981	1991	2001
All fields	42.8	50.3	45.4
Physical sciences	50.4	56.6	53.2
Mathematics	21.3	34.5	31.9
Computer sciences	29.7	49.4	47.2
Earth, atmospheric, and ocean sciences	50.2	66.2	64.1
Life sciences	59.6	65.5	56.6
Psychology	32.7	34.7	34.3
Social sciences	21.8	28.4	21.5
Engineering	51.0	63.2	56.8

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations. See appendix table 5-32.

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positions are less likely to receive Federal support than those in postdoc or other full-time positions (appendix tables 5-32 and 5-33). Overall, about 48 percent of those with recently earned doctorates (within 3 years of the survey) received Federal support. However, about 29 percent of those in full-time faculty positions received support, compared with about 73 percent of those in postdoc positions. The share of postdocs receiving Federal support was relatively low (about 42–57 percent) in some fields (e.g., the social sciences, mathematics, and engineering) and high (80 percent or more) in others (e.g., the physical sciences, computer sciences, and earth, atmospheric, and ocean sciences).

In 2001, young academics who had gained some experience (i.e., those who had received their doctorate 4 to 7 years earlier) received Federal support in proportions similar to those of the academic S&E doctoral workforce as a whole in most fields (appendix tables 5-32 and 5-33 and table 5-16).

Federal Support From Multiple Agencies

About 20 percent of academic S&E doctorate holders who report Federal support indicated they received support from more than one agency in the mid-1970s and early 1980s. This proportion peaked at 30 percent in 1991, and by 2001 declined to 26 percent (table 5-17). Although, as previously indicated, holders of recently awarded doctorates were more likely to receive Federal support than the overall academic S&E doctoral workforce, they were less likely to receive it from more than one agency.

Has Academic R&D Shifted Toward More Applied Work?

Emphasis on exploiting the intellectual property that results from the conduct of academic research is growing. (See next section, “Outputs of Scientific and Engineering Research: Articles and Patents.”) Among the criticisms raised about this development is that it can distort the nature of academic research by focusing it away from basic

Table 5-16
S&E doctorate holders employed in academia 4–7 years after receiving degree who received Federal support, by degree field: 1981, 1991, and 2001
(Percent)

Degree field	1981	1991	2001
All fields	46.5	57.4	46.1
Physical sciences	57.9	67.2	54.1
Mathematics	29.7	28.3	42.2
Computer sciences	52.4	66.2	49.2
Earth, atmospheric, and ocean sciences	57.2	76.6	54.1
Life sciences	64.0	70.6	56.4
Psychology	34.7	38.8	34.9
Social sciences	24.3	36.6	21.2
Engineering	65.6	73.2	58.3

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations. See appendix table 5-33.

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Table 5-17
S&E doctorate holders employed in academia receiving Federal support who received it from multiple agencies: Selected years, 1975–2001
(Percent)

S&E doctorate holders	1975	1981	1991	2001
All	20	19	30	26
Recent[a]	15	13	20	17

[a]Doctorate received at U.S. university within 3 years of survey.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations.

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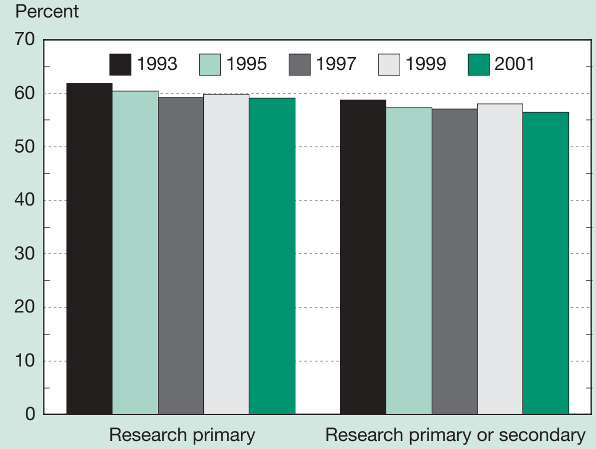
Figure 5-29
S&E doctorate holders in academia involved in research whose primary research activity is basic research: Selected years, 1993–2001



NOTE: S&E doctorate holders involved in research include those whose primary or secondary work activity is basic or applied research, development, or design.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations.

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research and toward the pursuit of more utilitarian, problem-oriented questions.

Did such a shift toward applied research, design, and development occur during the 1990s, a period when academic patenting and licensing activities grew considerably? By its very nature, this question is a difficult one to analyze, for a number of reasons. As indicated earlier in the chapter, it is often difficult to make clear distinctions among basic research, applied research, and development. Sometimes basic and applied research can be complements and embodied in the same research. Some academic researchers may obtain ideas for basic research from their applied research activities.

Two indicators can be examined to determine whether any large-scale changes occurred. One indicator is the share of all academic R&D expenditures directed to basic research. Appendix table 5-1 shows that the basic research share increased slightly between 1990 and 1996 and that there was hardly any change in this measure between 1998 and 2002. The second indicator is the response to a question S&E doctorate holders in academia were asked about their primary or secondary work activities, including four R&D functions: basic research, applied research, design, and development.

As figure 5-29 shows, for those employed in academia who reported research as their primary activity, involvement in basic research declined slightly between 1993 and 2001, from 61.9 percent to 59.1—a shift that barely reaches statistical significance. A similar shift occurred for all academic doctoral researchers (from 58.7 percent in 1993 to 56.5 in 2001). The available data, although limited, provide little evidence to date that pressures on academic institutions and faculty to change research agendas led to a shift toward more applied work.

Outputs of Scientific and Engineering Research: Articles and Patents

The products of academic research include trained personnel and advances in knowledge. Trained personnel are discussed earlier in this chapter and also in chapter 2. This section presents data on two additional indicators of scientific research output: scientific articles and patents received by U.S. academic institutions. In addition, it presents data on citations to previous scientific work contained in articles and patents.

Articles, patents, and citations provide indicators, albeit imprecise ones, of scientific output, the content and priorities of scientific research, the institutional and intellectual linkages within the research community, and the ties between scientific research and practical application. Data on articles, patents, and citations, used judiciously, enable meaningful comparisons of institutional sectors, scientific disciplines, and nations.

Articles are one key output for scientific research because publication has been the norm for disseminating and validating research results and is crucial for career advancement in most scientific fields. Data on the authorship of articles also provide information on the extent of research collaboration and on patterns and trends in collaboration across institutional, disciplinary, and national boundaries.

Citations provide another measure of scientific productivity by indicating how influential previous research has been. Patterns in citations can show links within and across institutional boundaries. Citations to scientific articles in U.S. patents provide indications of the degree to which technological innovations rely on scientific research.

The number of patents issued to U.S. universities is another indicator of the output of academic science. In addition, it is an indicator of the relationship between academic research and commercial application of new technologies.

Output of U.S.-authored scientific articles has flattened since the early 1990s, while article output grew strongly in Western Europe, Japan, and several East Asian countries during this period. The reasons for the change in the U.S. trend are unknown and are under investigation. Collaboration between institutional authors within and across national boundaries has grown considerably over the past 2 decades. Although the U.S. continues to have the largest share of internationally authored articles, this share has declined over the past 2 decades as countries have expanded and deepened their collaboration with other countries. Patenting and related activities by U.S. academic institutions continued to increase during the 1990s, suggesting the growing effort and success of universities to commercialize their research results and technology.

For a discussion of the nature of the data used in this section, see sidebar, "Data and Terminology."

Worldwide Trends in Article Output

The volume of articles published in the world's key S&E journals is an indicator of the output of scientific and technical research in the United States and other countries. The United States had the largest single share of articles in the world in 2001, accounting for approximately one-third of all articles. When the shares of Japan, Germany, the United Kingdom, and France are added to the United States, these five countries account for nearly 60 percent of all articles published in 2001. Adding other countries of the Organisation for Economic Co-operation and Development (OECD) and other high-income countries increases this share to more than 80 percent of world output (table 5-18). These countries generally also rank high on a per capita output basis. Their wealthy, technically advanced economies enable them to maintain pools of scientists and engineers and the scientific and technical infrastructures their work requires

Table 5-18
OECD share of world S&E article output: 2001
(Percent)

Country	Share
All OECD	82.0
United States	30.9
Japan	8.8
United Kingdom	7.3
Germany	6.7
France	4.8
Other OECD	23.4

OECD Organisation for Economic Co-operation and Development

NOTES: Country shares are based on articles credited to the institutional address of the country. For internationally authored articles, countries are credited the fractional contribution to the article.

SOURCES: Institute for Scientific Information, Science Citation Index and Social Sciences Citation Index; CHI Research, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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Data and Terminology

The article counts, coauthorship data, and citations discussed in this section are based on science and engineering articles, notes, and reviews published in a slowly expanding set of the world's most influential scientific and technical journals tracked by the Institute for Scientific Information (ISI) Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). These data are not strictly comparable to those presented in previous editions of *Science & Engineering Indicators,* which were based on a fixed ISI journal set. The advantage of the "expanding" set of journals is that it better reflects the current mix of influential journals and articles. The number of journals covered by ISI that published relevant material (i.e., articles, notes, or reviews) was 4,460 in 1988, 4,601 in 1993, 5,084 in 1998, and 5,262 in 2001.

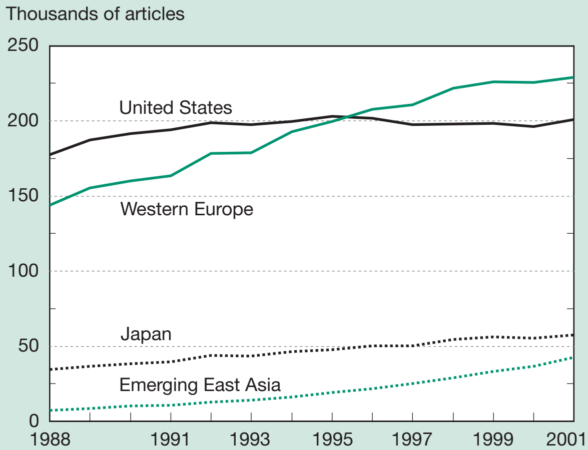
Field designations for articles in the ISI-tracked journals are determined by the classification of the journal in which an article appears. Journal classification, in turn, is based on the patterns of a journal's citations (appendix table 5-34).

SCI and SSCI give reasonably good coverage of a core set of internationally recognized scientific journals, albeit with some English-language bias. ISI coverage extends to electronic journals, including print journals with electronic versions and electronic-only journals. Journals of regional or local importance may not be covered, which may be salient for the categories of engineering and technology, psychology, the social sciences, the health sciences, and the professional fields, as well as for nations with a small or applied science base.

Author as used here means *institutional author.* Articles are attributed to countries and sectors by the author's institutional affiliation at the time of publication. If an institutional affiliation is not listed on the paper, it would not be attributed to an institutional author. Likewise, *coauthorship* refers to institutional coauthorship: a paper is considered coauthored only if its authors have different institutional affiliations or are from separate departments of the same institution. Multiple authors from the same department of an institution are considered as one institutional author. The same logic applies to cross-sectoral or international collaboration.

All data presented here derive from the Science Indicators database prepared for the National Science Foundation by CHI Research, Inc. The database excludes all letters to the editor, news pieces, editorials, and other content whose central purpose is not the presentation or discussion of scientific data, theory, methods, apparatus, or experiments.

Figure 5-30
Output of S&E articles by selected countries/regions: 1988–2001



NOTE: Emerging East Asia consists of China, Singapore, South Korea, and Taiwan.

SOURCES: Institute for Scientific Information, Science Citation Index and Social Sciences Citation Index; CHI Research, Inc., and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix table 5-35.

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and to provide relatively high levels of financial support for their S&E enterprises.[39]

World article output increased by almost 40 percent from 1988 to 2001, largely driven by growth in Western Europe, Japan, and several emerging East Asian S&T centers (South Korea, Singapore, Taiwan, and China). In contrast, growth in article output by U.S. authors was markedly slower and remained essentially flat after 1992 (figure 5-30). Flattening of output in almost all fields drove the U.S. trend (table 5-19).

The basic picture of broad article trends shows that the nations with the greatest wealth and the most mature S&T infrastructures lost some ground, in relative terms, to developing nations with moderate income levels.[40] Low-income nations experienced little change in their shares of the world's S&E publications (figure 5-31).

Western Europe's article output grew by about two-thirds from 1988 to 2001 and surpassed that of the United States in 1997. Output gains were substantial across most countries, especially many of the smaller and/or newer members of the European Union (EU) (figure 5-30 and appendix table 5-35). This growth may reflect, at least in part, EU and regional programs to strengthen the S&T base, as well as these nations' individual efforts.[41]

Japan's article output increased steadily over the period. It rose at approximately the same pace as Western Europe's, resulting in a two-thirds growth in output. This growth coincided with a substantial increase in Japan's R&D expenditures.

East Asian authors in China, South Korea, Singapore, and Taiwan produced S&E articles at a sharply accelerating pace, attesting to the rapid scientific and technological progress of these economies. Over the 14-year period covered here, article output rose almost 5-fold in China, 6-fold in Singapore and Taiwan, and 14-fold in South Korea. This pushed their collective share of the world total from 1.5 percent in 1988 to 6.6 percent in 2001. On a per capita output basis, China remains well below the world average, whereas the other three rank well above it (table 5-20).

Table 5-19
U.S. article output, by S&E field: Selected years, 1988–2001

Field	1988	1991	1993	1995	1997	1999	2001
All fields	177,662	194,015	197,397	202,887	197,531	198,524	200,870
Clinical medicine	55,016	59,488	61,312	63,367	62,676	63,190	63,709
Biomedical research	27,455	31,177	33,117	35,048	33,661	33,423	34,041
Biology	12,862	13,898	12,671	12,664	12,027	11,271	12,499
Chemistry	13,186	14,681	15,089	14,915	14,375	14,491	14,342
Physics	18,023	20,515	19,602	19,709	18,048	18,074	17,385
Earth/space sciences	8,053	9,113	9,830	10,886	10,540	11,209	11,272
Engineering/technology	11,817	12,838	13,303	13,801	12,907	13,564	13,889
Mathematics	3,880	3,382	3,453	3,190	3,051	3,561	3,657
Social/behavorial sciences	27,370	28,922	29,019	29,307	30,246	29,742	30,075

NOTE: Social/behavioral sciences include social sciences, psychology, health sciences, and professional fields.

SOURCES: Institute for Scientific Information, Science Citation Index and Social Sciences Citation Index; CHI Research, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix table 5-36.

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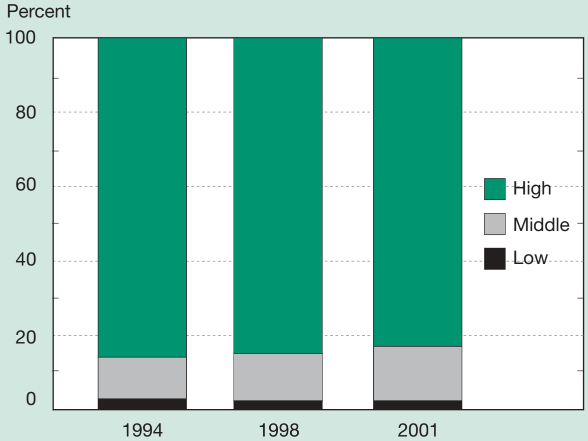
[39]Also see chapter 2, "Higher Education in Science and Engineering"; chapter 4, "U.S. and International Research and Development: Funds and Technology Linkages"; and chapter 6, "Industry, Technology, and the Global Marketplace."

[40]As determined by the World Bank, which classifies countries as high, middle, or low on the basis of their per capita income.

[41]These include the EU 5-year Framework and programs of other pan-European organizations, such as EUREKA, which encourages partnerships between industry, universities, and research institutes with the goal of commercializing research. See European Commission (2001) for a fuller treatment.

Figure 5-31
World S&E articles, by income level of countries: 1994, 1998, and 2001



NOTES: Income classification determined by World Bank, based on per capita income level. Countries without World Bank income classification are excluded.

SOURCES: Institute for Scientific Information, Science Citation Index and Social Sciences Citation Index; CHI Research, Inc.; National Science Foundation, Division of Science Resources Statistics, special tabulations, and World Bank, *World Development Indicators 2002* (Washington, DC, 2002).

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The output volume of Central and South America grew by more than 8 percent per year. Three countries—Argentina, Brazil, and Chile—generated more than 85 percent of the region's articles in 2001, and all had moderately high per capita incomes, relatively large pools of scientists and engineers, and undertook recent reforms of their economies and scientific enterprises (NSF/SRS, 2000). Article output in Western Asia is influenced by Indian publications, which started to rise in the late 1990s after years of stagnation. India's science community, however, has renewed its debate about the health of its science enterprise in light of much higher S&E article growth in the emerging East Asian countries.[42] Scientists in North Africa and the Middle East increased their article output by about 3 percent annually, but increases in Israeli output, accounting for the bulk of the region's publications, lagged behind the overall pace of growth. The output of countries in Sub-Saharan Africa, including South Africa, stagnated or fell; the region accounted for less than 1 percent of world output.

Output in Eastern Europe and Central Asia fell almost 20 percent during this period, with article volume in countries of the former USSR dropping by one-third (appendix table 5-35). This sharp decline mirrors the economic and political difficulties that affected their scientific enterprise, including significant cuts in their R&D spending. In contrast, several Eastern European countries had substantial gains in output in the latter half of the 1990s.

[42]See Arunachalam (2002). The author notes that India's world share of scientific publications has fallen while South Korea and China have rapidly increased their growth and world share of scientific articles.

Table 5-20
Per capita output of S&E articles, by country/economy: 1999–2001

Country/economy	Articles/1 million inhabitants
Switzerland	1,165.0
Sweden	1,139.3
Israel	1,055.2
Finland	960.5
Denmark	932.2
United Kingdom	821.9
Netherlands	800.5
Australia	794.2
United States	722.2
Norway	720.0
Singapore	590.3
France	538.6
Germany	530.5
OECD	490.3
Japan	445.6
Ireland	429.9
Spain	382.7
Italy	371.4
Taiwan	330.3
Czech Republic	241.4
South Korea	206.8
Portugal	191.3
Poland	139.9
Russia	116.4
Worldwide[a]	108.8
Bulgaria	103.7
Argentina	77.8
Chile	75.7
South Africa	55.8
Brazil	38.8
Lebanon	37.3
Mexico	31.8
Egypt	23.2
Costa Rica	22.8
Malaysia	21.9
China	14.8
Iran	13.6
Thailand	10.8
India	10.8
Kenya	8.6
Guatemala	1.5

[a]Excludes Bosnia, Taiwan, and several small countries and island countries because of lack of population data.

NOTES: Countries/economies listed in descending rank order by average of per capita output for 1999–2001. Counts based on fractional assignments (e.g., an article with two authors from different countries is counted as half an article for each country).

SOURCES: Institute for Scientific Information, Science Citation Index and Social Sciences Citation Indexes; CHI Research, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations; population data (except Taiwan)—World Bank, *World Development Indicators 2002* (Washington, DC, 2002); Taiwan population—U.S. Central Intelligence Agency, *The World Factbook 2002* (Washington, DC, 2002).

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Flattening of U.S. Article Output

The number of S&E articles by authors based in the United States has remained flat since 1992, even though real R&D expenditures and the number of researchers continued to rise. This trend diverged from that of most other OECD countries during this period and is a reversal from 3 prior decades of consistent growth (figure 5-32). The reasons for this development remain unknown. (See sidebar, "Exploring Recent Trends in U.S. Publications Output.")

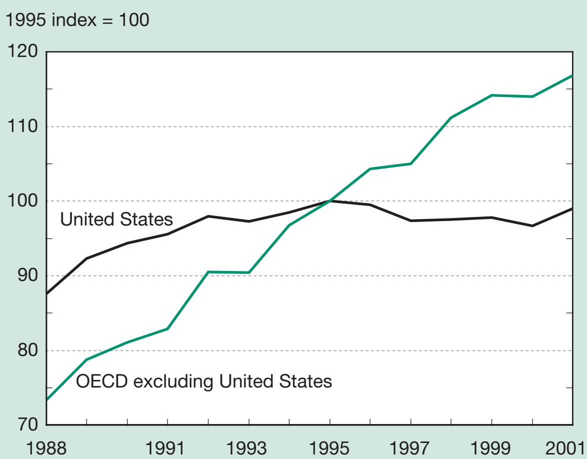
This phenomenon is not limited to the United States. Three mature industrial countries with significant article outputs—Canada, the United Kingdom, and the Netherlands—experienced a similar flattening of article output, starting in the latter half of the 1990s (figure 5-33). In addition, in most other OECD countries, increases in article output were slower in the second half of the 1990s than in the first half.

Table 5-19 shows that in most individual fields, the growth trends in U.S.-authored articles followed similar trajectories. The number of articles continued to rise into the 1990's but remained constant thereafter. Chemistry and physics articles declined after 1992, with a particularly steep drop in physics. Output in biology was stagnant over the entire 1988–2001 period. Output in the earth and space sciences increased, although the increase slowed toward the end of the period.

The growth trend in articles from the U.S. academic sector, which accounts for almost three-fourths of U.S. articles, was similar to that of overall output (figure 5-34 and appendix table 5-36). Output flattened across most individual scientific fields starting in the mid-1990s. Physics articles, however, declined significantly after 1994. The field distribution of scientific articles in the U.S. academic sector remained largely unchanged during this period (figure 5-35 and appendix table 5-36).

Article output of other sectors followed a similar growth path. In the Federal Government, output declined after 1994,

Figure 5-32
Output of S&E articles for United States and OECD: 1988–2001



OECD Organisation for Economic Co-operation and Development

SOURCES: Institute for Scientific Information, Science Citation Index and Social Sciences Citation Index; CHI Research, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix table 5-35.

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Exploring Recent Trends in U.S. Publications Output

Publication of research results in the form of articles in peer-reviewed journals is the norm for contributing to the knowledge base in many scientific disciplines. It has become customary to track the number of peer-reviewed articles as one, albeit imperfect, indicator of research output. In recent years, international use of this and related indicators has become widespread, as countries seek to assess their relative performance.

The recent flattening in the output of U.S. science and engineering publications contrasts with continued increases in real research and development expenditures and number of researchers. The reasons for these divergent trends remain obscure. To explore what factors may be implicated in this development, the National Science Foundation is undertaking a special study that addresses the following questions:

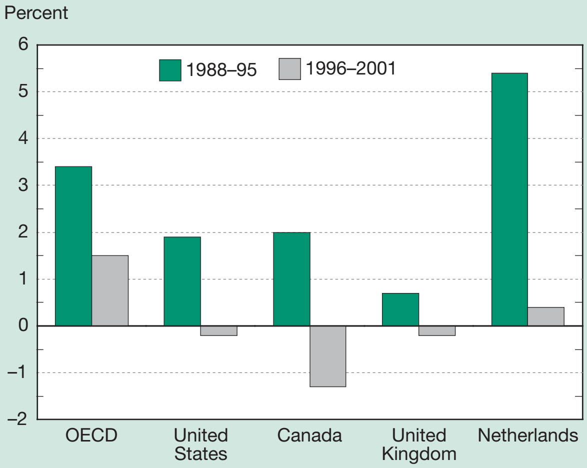
- What key trends affected the scientific publishing industry in the 1990s?
- Is the apparent change in output trends real or an artifact of the indicators used?
- What are the characteristics of the change in the trend?
- What factors may contribute to it, and what evidence exists about whether and how these factors are involved?

The project analyzes key developments in scientific publishing, with particular focus on the 1990s, to establish the broad outlines of the environment in which scientific publishing in the United States is taking place. It also includes methodological research that focuses directly on the publications themselves. This research will examine the effects of measurement approaches, journal coverage, and other technical considerations on indicators of publications output.

Work will also be undertaken to determine where in the U.S. research system these trend changes are found; what institutional, demographic, funding, or other factors may be contributing to them; and what the nature of these relationships may be. Field differences in publication patterns will be a major theme of the analysis. The results of the study are expected to be published in *Science & Engineering Indicators – 2006* and in special reports.

primarily because of a decrease in articles in the life sciences and physics. Industry output also declined during the 1990s, with significant declines in the fields of chemistry, physics, and engineering and technology. The exception to this trend was the nonprofit sector, in which article share grew during the late 1990s because of an increasing number of articles in clinical medicine.

Figure 5-33
Average growth in S&E articles for selected countries: 1988–2001



OECD Organisation for Economic Co-operation and Development

SOURCES: Institute for Scientific Information, Science Citation Index and Social Sciences Citation Index; CHI Research, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix table 5-35.

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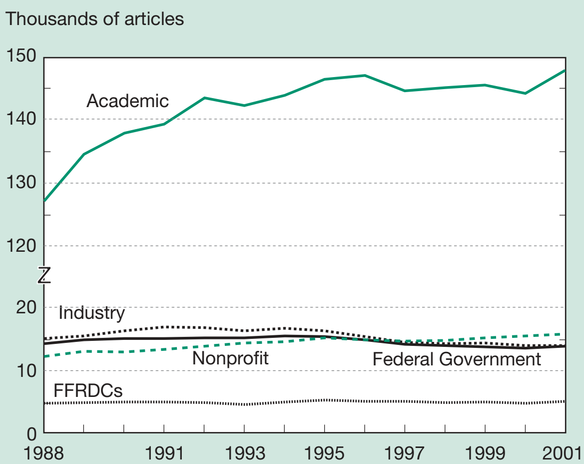
Field Distribution of Articles

The field distribution of scientific articles changed little between 1988 and 2001. The life sciences dominated the portfolio of the OECD countries, including the United States, and of Central and South America and Sub-Saharan Africa (figure 5-36 and appendix tables 5-37 and 5-38). The share of life sciences is noticeably smaller in the Middle East (excluding Israel), Eastern Europe/Central Asia, and the four emerging Asian countries, with the physical sciences and engineering and technology more dominant.

Scientific Collaboration

Coauthorship of S&E articles reveals the changing social structure of the conduct of scientific research. In most fields, articles are increasingly authored by research teams that span academic departments or institutions, cross-sectoral boundaries, or include international collaborators. Collaboration on S&E articles, as measured by articles with more than one institutional author, has increased significantly in the past 2 decades. Collaboration on scientific articles has intensified across institutional boundaries in the United States and between countries. The rise in domestic and international collaboration has been driven by several factors:

Figure 5-34
Output of S&E articles, by selected U.S. institutional sectors: 1988–2001



FFRDC federally funded research and development center

NOTES: Article counts are based on fractional assignments; for example, an article with two authors from different sectors is counted as one-half of an article for each sector. Articles with coauthors from more than one country are counted similarly.

SOURCES: Institute for Scientific Information, Science Citation Index and Social Sciences Citation Index; CHI Research, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix table 5-36.

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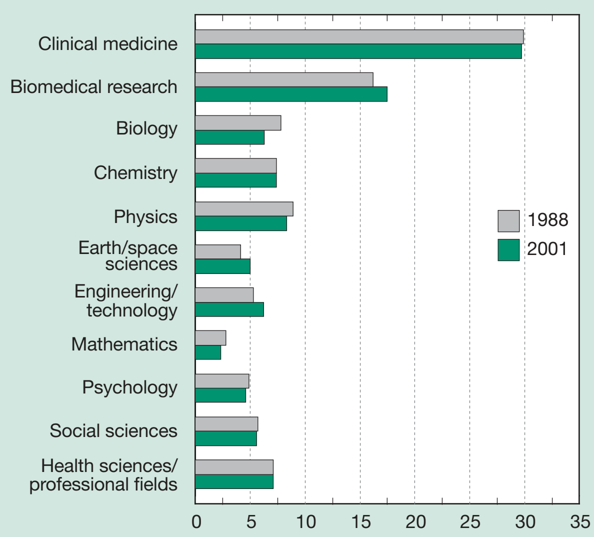
Figure 5-35
Field distribution of U.S. S&E articles from academia: 1988 and 2001



NOTES: Field classification by CHI Research, Inc. Computer sciences are included in engineering/technology.

SOURCES: Institute for Scientific Information, Science Citation Index and Social Sciences Citation Index; CHI Research, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix table 5-36.

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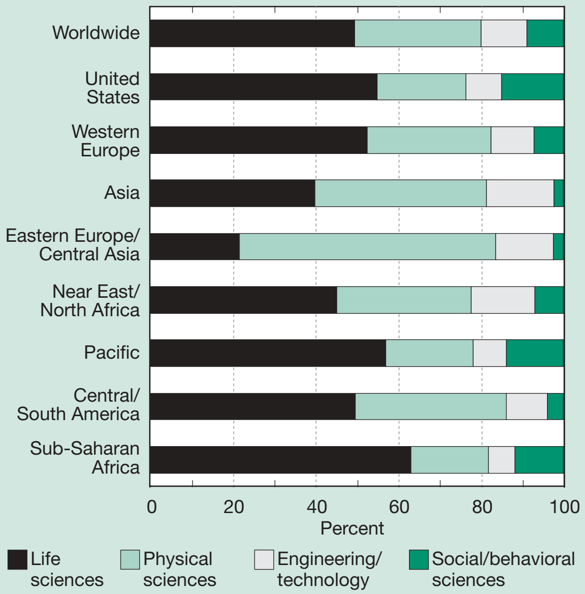
Figure 5-36
Field distribution of S&E articles, by region: 2001



NOTES: Life sciences include clinical medicine, biomedical research, and biology. Physical sciences include chemistry, physics, and earth and space sciences. Social and behavioral sciences include social sciences, psychology, health sciences, and professional fields. Computer sciences are included in engineering/technology.

SOURCES: Institute for Scientific Information, Science Citation Index and Social Sciences Citation Index; CHI Research, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix table 5-38.

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- **Scientific need.** Cutting-edge science in many fields increasingly involves a broad range of knowledge, perspectives, and techniques that extend beyond a given discipline or institution. Moreover, the scope, cost, and complexity of some of today's scientific problems, such as mapping the human genome, studying global environmental trends, or constructing an observatory in space, invite and often compel domestic and international collaboration.
- **Technological advances.** Advances in transportation and information and communications technologies have reduced geographical and cost barriers to domestic and international collaboration. Air travel and international telephone calls have become relatively inexpensive. E-mail greatly facilitates collaboration by allowing rapid exchange of information and reducing the need for frequent face-to-face meetings or telephone exchange. The increasing use of high-capacity computer networks allows researchers to exchange data files and even to conduct experiments from a distance. Improvements in software permit researchers to share research findings, conduct research online without requiring a centralized laboratory, and conduct virtual experiments.
- **Education.** Study abroad appears to contribute to growth in international collaboration.[43] Relationships established between foreign students and their teachers can form the basis of future collaboration after the students return to their native country. As an important supporting element in other factors driving collaboration, information technology greatly facilitates this type of collaboration.
- **Falling political barriers.** The end of the Cold War allowed countries to establish and/or renew political, economic, and scientific ties. It also led to the addition of new members to the world's countries.[44]
- **Government policies.** A range of nations have adopted policies to encourage scientific collaboration, motivated by the belief that collaboration maximizes and leverages their public investment in research funding, increases progress in S&T, boosts domestic capability, and/or speeds the transfer of knowledge. These policies include public R&D funding requirements to encourage or require domestic or international collaboration and formal international S&T agreements with other countries.

Collaboration Within the United States

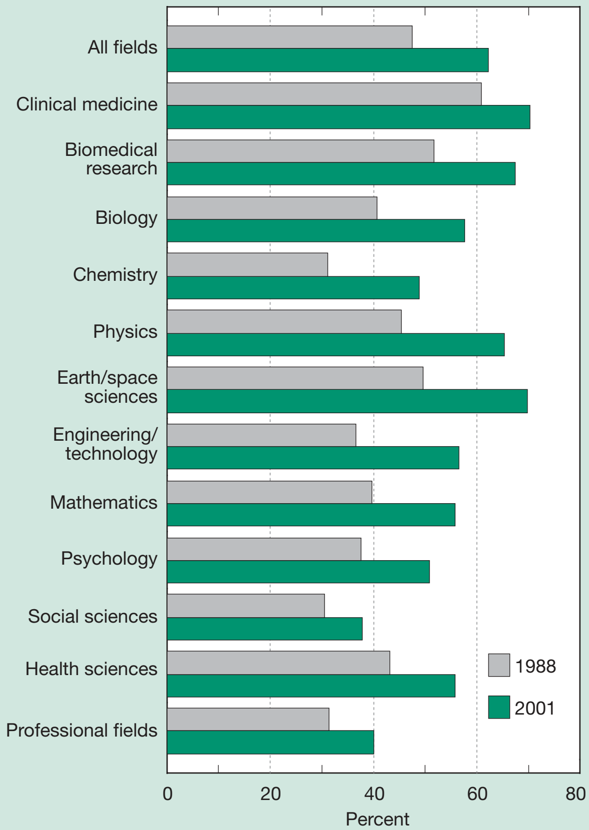
Scientific collaboration across institutional boundaries in the United States is extensive and has continued to intensify. The share of coauthored articles increased from 48 percent of all U.S. articles in 1988 to 62 percent in 2001 (figure 5-37 and appendix tables 5-39 and 5-40). The level of institutional collaboration by field, in terms of the share of coauthored articles, was highest in clinical medicine, biomedical research, the earth and space sciences, and physics, and lowest in chemistry, psychology, the social sciences, and the professional fields (figure 5-37). According to an earlier study, these variations may reflect the nature, culture, and complexity of the research by field and the level and requirements of government funding.[45]

Government policies have reinforced collaboration by requiring or encouraging collaboration as a condition of research funding and by announcing programs targeted to encouraging cross-sectoral collaboration [e.g., between industry and universities or federally funded research and development centers (FFRDCs)]. This is particularly evident in the academic sector, where collaboration has been increasing between departments within an institution, between universities, and between universities and other sectors, including the government, industry, and the nonprofit sector.

In 2001, articles with authors from different institutional sectors (academic, industry, Federal Government, nonprofit institutions, FFRDCs, and state and local government) accounted for more than one-third of the academic sector's coauthored articles and more than three-fourths of those of the other sectors (table 5-21 and appendix tables 5-41 and

[43]See chapter 2, "Higher Education in Science and Engineering."
[44]Part of the increase reflects the creation of new countries, such as those formed from the former Soviet Union, during this period. The volume and share of international articles, however, has continued to rise since the early 1990s.
[45]See De Solla Price (1986), pages 77–79.

Figure 5-37
Extent of collaboration on U.S. S&E articles, by field: 1988 and 2001



NOTES: Number of S&E articles with multiple institutional authors, including foreign institutions, as share of total S&E articles. Field volume is in terms of whole counts, where each collaborating institutional author is assigned an entire count. Computer sciences are included in engineering/technology.

SOURCES: Institute for Scientific Information, Science Citation Index and Social Sciences Citation Index; CHI Research, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix tables 5-39 and 5-40.

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5-42). The academic sector was at the center of cross-sectoral collaboration, represented in more than 80 percent of the articles originating in other sectors. Patterns of cross-sectoral collaboration are field specific, centered around a key sector on the basis of shares that substantially exceed the average of all articles:

- ♦ The nonprofit sector is a key collaborator with academia and FFRDCs in clinical medicine, a field in which it has a large share of article output relative to its overall share.
- ♦ Industry is a significant collaborator with academia in chemistry and partners with the Federal Government and academia in engineering and technology.
- ♦ The Federal Government is a key collaborator with academia and FFRDCs in the earth and space sciences.

International Collaboration

The international nature of science and its increasing globalization are reflected in the growth of international collaboration in scientific and technical research. Trends in international coauthorship of research articles in leading S&E journals provide a measure of the extent of international collaboration. The number of collaborative articles (i.e., those with institutional authors from more than one country) has greatly increased over the past 2 decades, and they constitute a larger proportion of all articles than in the past.

From 1988 to 2001, the total number of internationally coauthored articles more than doubled, increasing in share from 8 to 18 percent of all S&E articles. This rise has been driven by intensified collaboration among the dominant centers of S&E publishing, the United States, Western Europe, and Japan. It also reflects an increase in collaboration between these dominant centers and developing and emerging economies in Asia, Eastern Europe, the Near East, North and Sub-Saharan Africa, and Latin America. Finally, it reflects the development of an East Asian area of collaboration centered in China.

U.S. authors participate in the majority of internationally coauthored articles, and they collaborate with authors around the world. However, as other countries expanded the number and reach of their international collaborations, the U.S. share of internationally coauthored papers has fallen since the late 1980s. The extent of U.S. collaboration with scientists from other countries is shown in their growing shares of coauthorships on U.S. articles. Authors from Western European countries are well represented, and several emerging economies, notably China and South Korea, have also become major collaborators with the United States.

U.S. Role in International Scientific Collaboration. The extent of a country's influence on world scientific developments can be broadly indicated by the range of its international connections, measured here by the volume of internationally coauthored articles in which its authors participate. U.S.-based authors were represented in 44 percent of all internationally coauthored articles in 2001. In terms of number of collaborative partners, the United States collaborated with 166 of 180 countries that collaborated on any scientific article in 2001 (table 5-22 and appendix table 5-43). U.S. scientists collaborated in 18 to 42 percent of the internationally coauthored articles of most Western European countries. U.S. participation rates were higher in articles by Asian scientists, particularly those from China, the Asian newly industrialized economies (NIEs) of Hong Kong, Singapore, South Korea, and Taiwan, and the two countries with low overall rates of international collaboration, India and Japan (table 5-23 and appendix table 5-44).

With emerging and developing countries, U.S. collaboration is also significant and tends to be relatively high with countries that have significant regional output, such as Argentina, Brazil, and South Africa. The exception is Eastern Europe, where the U.S. share is generally lower than that

Table 5-21
U.S. cross-sectoral collaboration: 2001
(Percent)

Sector	All sectors	Academic	Industry	Federal Government	Nonprofit institutions	FFRDCs	State and local government
Academic	37	na	26	32	37	11	6
Industry	76	83	na	17	17	6	3
Federal Government	80	87	15	na	15	5	4
Nonprofit institutions	79	91	13	13	na	2	4
FFRDCs	80	85	14	14	7	na	0
State/local government	92	86	12	20	23	1	na

na not applicable
FFRDC federally funded research and development center

NOTES: Shares based on whole counts of publications, where each institutional author on a coauthored article is assigned a whole count. This counting methodology results in the sum of sector shares exceeding 100 percent because some coauthored articles involve collaboration across more than two sectors.

SOURCES: Institute for Scientific Information, Science Citation Index and Social Sciences Citation Index; CHI Research, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix table 5-42.

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of most other countries, ranging from 12 to 29 percent for almost all countries in this region.

The international collaborative activities of other countries generally grew more rapidly than those of the United States, resulting in an erosion of the relative U.S. share in these collaborations, although not their absolute number. The U.S. share of most countries' internationally authored papers was lower in 2001 than in 1988 (table 5-23 and appendix table 5-44). This pattern suggests that new centers of activity and collaboration are evolving outside of the United States. Among the major producers, the largest relative decline in U.S. collaboration was with Israel and Japan. These countries expanded their collaboration with many Western European countries and Russia; Japan also increased its collaboration with several Asian countries. Among emerging countries, the U.S. share in the Asian NIEs declined as these countries increased their ties with other Western European and other Asian countries, chief among these being China.

However, in an exception to this general trend, U.S. participation in China's internationally coauthored articles continued to rise, even as China's article output more than tripled in volume during the brief span from 1994 to 2001. Other exceptions included collaboration with scientists in Russia, the Czech Republic, Poland, and Ukraine. The rise in the U.S. share of these countries' international collaborations may reflect the effects of U.S. and other programs targeted to this goal. For example, several U.S. Federal agencies, including NSF, DOE, and NIH, have current or former programs to help fund collaborative research. In addition, the other organizations, including the EU, Civilian Research and Development Foundation (CRDF), and the North Atlantic Treaty Organisation (NATO), have programs that allow or encourage U.S. scientific collaboration with Eastern Europe.

Extent of International Collaboration on U.S. Scientific Articles. The degree to which other countries' scientific establishments are influential in the scientific and technical developments of the United States can be measured broadly by the role internationally coauthored articles play in the output of U.S. S&E articles. By 2001, 23 percent of all U.S. articles had at least one non-U.S. coauthor, compared with 10 percent in 1988. By field, international collaboration was highest in physics, the earth and space sciences, and mathematics, ranging from 35 to 38 percent of U.S. articles (figure 5-38). International collaboration rates were much lower in the social and behavioral sciences at about 10 percent.

The countries with the highest rates of collaboration with the United States were largely those with mature S&T systems. The top 15 collaborators with the United States included several Western European countries, Japan, Canada, China, South Korea, and Russia (table 5-24). Expansion of such ties has been particularly rapid for China, which vaulted from 14th to 7th largest collaborator during the period,[46] and South Korea, which moved from 17th to 12th. The patterns of international collaboration with the United States also appear to reflect the ties of foreign students who received advanced training in the United States (figure 5-39).[47]

International Collaboration Outside the United States

The development of scientific collaboration beyond the boundaries of mature industrial economies is illustrated by the expansion of collaborative ties among the other nations. International collaboration in the rest of the world grew significantly in terms of volume and share of internationally coauthored articles relative to all S&E articles between 1988

[46]The addition of Hong Kong's coauthored articles in 2001, which were counted separately from China's in 1994, slightly boosted China's share. Were Hong Kong included in China in 1994, however, China's rank would have been unchanged.

[47]There is a moderately high correlation ($r^2 = 0.45$) between the number of U.S. Ph.D.s awarded by country to foreign-born students in 1992–96 and the volume of papers coauthored by the United States and those countries in 1997–2001.

Table 5-22
Breadth of international S&E collaboration, by country/economy: 1994 and 2001

	Collaborating countries	
Country/economy	1994	2001
Developed		
United States	154	166
France	140	152
United Kingdom	143	150
Germany	125	130
Netherlands	115	127
Italy	114	121
Canada	119	120
Spain	88	116
Switzerland	112	116
Japan	97	114
Belgium	100	112
Australia	93	106
Sweden	110	102
Denmark	83	100
Austria	73	93
Norway	64	87
Israel	71	86
Portugal	51	86
Greece	68	82
Finland	73	81
Ireland	57	71
New Zealand	55	66
Emerging/developing		
China	78	103
Brazil	85	102
India	90	101
South Africa	58	95
Mexico	69	89
Russia	89	88
Poland	73	79
South Korea	52	78
Argentina	58	76
Hungary	64	74
Czech Republic	65	72
Kenya	50	69
Thailand	59	69
Egypt	72	67
Taiwan	46	66
Chile	57	64
Indonesia	37	60
Singapore	36	57
Slovakia	51	54
Nigeria	59	52
Croatia	44	52
Pakistan	37	52
Estonia	29	47
Lebanon	19	46
Philippines	38	46
Vietnam	25	46
Uganda	31	44
Iran	20	44

NOTE: Data are number of countries that have jointly authored articles (based on institutional address) with indicated countries.

SOURCES: Institute for Scientific Information, Science Citation Index and Social Sciences Citation Index; CHI Research, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix table 5-43.

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Table 5-23
International coauthorship with United States, by country/economy: 1988, 1994, and 2001
(Percent)

	U.S. share of coauthored articles		
Country/economy	1988	1994	2001
Emerging/developing			
Taiwan	76	72	58
South Korea	65	65	57
Mexico	56	49	42
Turkey	33	37	41
Chile	42	36	39
Brazil	42	40	39
China	49	34	37[a]
India	37	39	37
Thailand	34	35	35
Kenya	38	36	35
Argentina	35	33	35
Philippines	46	29	33
Egypt	34	34	32
South Africa	39	33	31
Singapore	23	32	30
Hungary	27	31	29
Zimbabwe	21	31	29
Nigeria	39	23	27
Poland	24	24	27
Iran	43	39	26
Indonesia	26	34	26
Russia	na	22	24
Estonia	na	19	20
Czech Republic	na	17	20
Vietnam	na	4	16
Malaysia	23	19	14
Cuba	4	10	9
Morocco	19	14	7
Developed			
Canada	55	53	53
Israel	67	60	52
Japan	53	49	43
Australia	40	36	37
Italy	35	34	32
Switzerland	31	31	31
United Kingdom	33	31	31
Germany	33	30	30
Netherlands	32	30	30
Denmark	31	29	29
Finland	32	34	29
Sweden	37	30	27
Spain	29	27	27
Norway	31	30	26
France	29	27	26
Belgium	26	24	23
Ireland	23	25	18

na not applicable

[a]Includes articles from Hong Kong.

NOTES: Countries listed in descending order by U.S. share of all internationally coauthored articles in 2001. Article volume is on a whole-count basis (i.e., each collaborating country is assigned an entire count on international articles).

SOURCES: Institute for Scientific Information, Science Citation Index and Social Sciences Citation Index; CHI Research, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix table 5-44.

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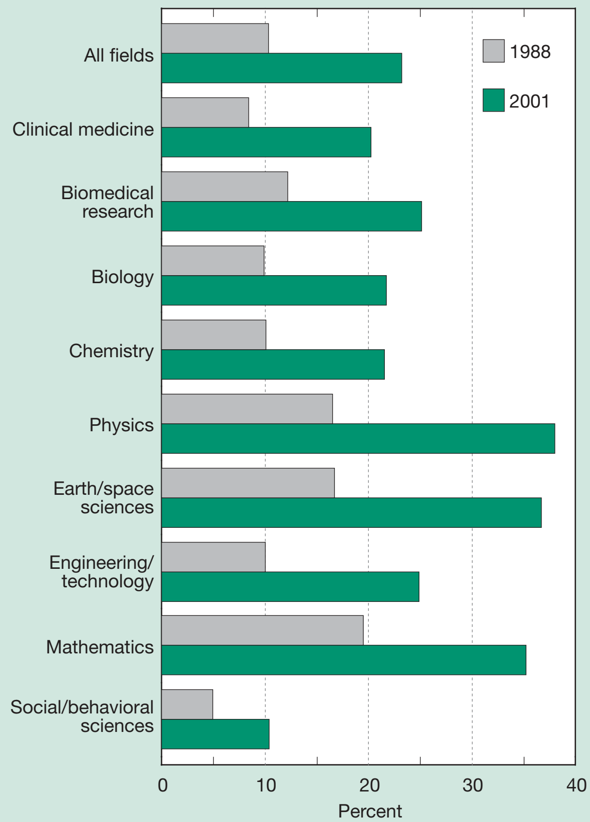
Figure 5-38
Extent of international collaboration on U.S. S&E articles, by field: 1988 and 2001



NOTES: International collaboration is the number of U.S. articles with at least one non-U.S. coauthor as a share of the total number of U.S. articles. Field volume is in whole counts, where each institutional coauthor is assigned an entire count. Social/behavioral sciences include social sciences, psychology, health sciences, and professional fields. Computer sciences are included in engineering/technology.

SOURCES: Institute for Scientific Information, Science Citation Index and Social Sciences Citation Index; CHI Research, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix tables 5-39 and 5-40.

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Table 5-24
Top countries collaborating with United States on S&E articles: 1994 and 2001
(Percent of U.S. internationally authored articles)

	1994		2001	
Rank	Country	Percent	Country	Percent
1	Canada	12.6	Germany	13.5
2	United Kingdom	12.1	United Kingdom	12.9
3	Germany	12.0	Canada	11.1
4	Japan	10.0	Japan	10.2
5	France	8.8	France	8.7
6	Italy	6.7	Italy	6.9
7	Israel	4.7	China[b]	4.7
8	Switzerland	4.1	Australia	4.7
9	Netherlands	4.1	Netherlands	4.3
10	Australia	3.8	Spain	3.8
11	Sweden	3.5	Switzerland	3.8
12	Russia	3.3	South Korea	3.6
13	Spain	2.8	Russia	3.5
14	China[a]	2.1	Israel	3.5
15	Belgium	2.0	Sweden	3.4

[a]Excludes Hong Kong. Including Hong Kong would add 0.5 percentage point.
[b]Includes Hong Kong.

NOTES: Article volume is on a whole-count basis (i.e., each collaborating country is assigned an entire count on international articles). Shares are on the basis of the number of country's coauthorships as a fraction of U.S. internationally authored articles.

SOURCES: Institute for Scientific Information, Science Citation Index and Social Sciences Citation Index; CHI Research, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix table 5-44.

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and 2001. This increase was the result of an expansion in the volume of existing collaboration among countries and a substantial increase in the number of new country partnerships (figure 5-40).

In 2001, nearly 60 countries had ties to at least 50 or more other nations, compared with 43 in 1994. Emerging and developing countries generally expanded their collaborative ties more than mature science producers (table 5-22 and appendix table 5-43).[48] Although international ties greatly expanded, many countries, particularly those with smaller science establishments, tend to collaborate with relatively few developed countries.

In Western Europe, articles with at least one international coauthor accounted for 33 percent of all articles in 2001, up from 17 percent in 1988 (figure 5-40). Countries in this region, many of which had extensive ties during the previous decade, continued to expand their partnerships. There were 10 Western European countries with ties to 100 or more nations in 2001, a clear sign of this region's extensive scientific collaboration with other nations (table 5-22). Countries that had a particularly rapid expansion in collaborative partners included Spain, Norway, Portugal, Turkey, and Ireland; these countries also had rapidly expanding article output. Much of the high degree of international collaboration in Western Europe (as measured by the share of the countries' articles with institutional coauthors from other European countries) reflects the extensive intraregional collaboration centered on France, Germany, Italy, Spain, and the United Kingdom (appendix table 5-45). The extent of and increase in intra-European collaboration in part reflects historical ties and in part the effects of EU programs that encourage collaboration.

In Asia, the share of international articles increased from 11 percent of all articles in 1988 to 21 percent in 2001, reflecting an expansion in international coauthorship by China, India, Japan, and emerging countries such as Malaysia and Indonesia (figure 5-40). Japan, China, and India saw

[48]Twenty-six nations have formed since 1990, primarily as a result of the breakup of the former Soviet Union, but almost all were formed before 1994. Thus, new countries are not a factor in the expansion of collaboration on scientific articles between 1994 and 2001.

Figure 5-39
Relationship of advanced training to international collaboration with United States: 1992–96 and 1997–2001

NOTE: Countries with at least 0.02 percent share of internationally coauthored articles are included. Coauthored articles are on the basis of whole counts, where each country is assigned an entire count for coauthorship on an S&E article with the United States.

SOURCES: Institute for Scientific Information, Science Citation Index and Social Sciences Citation Index; CHI Research, Inc; and National Science Foundation, Division of Science Resources Statistics, Survey of Earned Doctorates, special tablulations.

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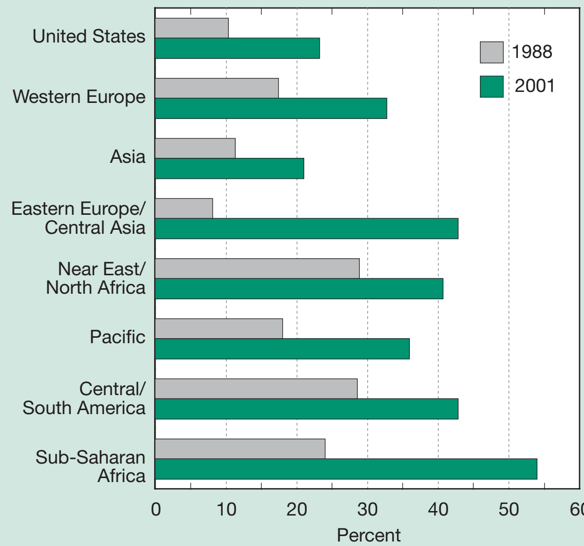
Figure 5-40
International S&E collaboration, by region: 1988 and 2001



NOTES: International collaboration is the number of articles with at least one foreign coauthor as a share of the total number of articles from the region or country. Article volume is in whole counts, where each institutional coauthor is credited with a whole count.

SOURCES: Institute for Scientific Information, Science Citation Index and Social Sciences Citation Index; CHI Research, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations

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their collaborative ties extend to more than 100 countries between 1994 and 2001 (table 5-22).

The rate of international coauthorship of the East Asian economies of China, Taiwan, and South Korea stayed constant during this period at 8–30 percent of their rapidly increasing output (appendix table 5-44). However, their collaboration expanded to a larger number of countries, primarily major science producers, as their share of U.S.-coauthored articles declined from very high levels. Greater intraregional collaboration in Asia, centered particularly on China, was also a significant factor in the increase in international collaboration for these three NIEs (appendix table 5-46).

In other emerging and developing regions, such as Central and South America, countries expanded their collaboration with Western Europe and Japan and also increased their collaboration with countries in their own region (appendix table 5-47). Intraregional collaboration in Central and South America, however, is more modest and limited than in Western Europe and Asia.

International Citation of S&E Articles

Citations in S&E articles generally credit the contribution and influence of previous research to a scientist's own research. Trends in citation patterns by region, country, scientific field, and institutional sector are indicators of the perceived influence and productivity of scientific literature across institutional and national boundaries.[49] Citations may also provide an indication of the access to and visibility of scientific research across national boundaries.

The trends and patterns in the citation of scientific literature by country are similar to those in the output of S&E articles. On the basis of volume, the major producers of scientific articles—the United States, Western Europe, Japan, and other OECD countries—are those whose S&E literature is most cited (table 5-25 and appendix table 5-48). In 2001, the United States' share of the world's output of cited S&E literature was 44 percent, the largest single share of any country. Collectively, the OECD countries accounted for 94 percent of the world's cited scientific literature in 2001 (table 5-25), a share that exceeded these countries' share of the world output of S&E articles (see table 5-18).

Citation of the S&E literature of the OECD countries was also high relative to these countries' share of world output of S&E articles. When the United States' share of literature cited by the rest of the world is adjusted for its share of published literature, its *relative citation index,* it is the most cited

[49]Citations are not a straightforward measure of quality because of authors' citation of their own previous articles; authors' citation of the work of colleagues, mentors, and friends; and a possible nonlinear relationship between a country's output of publications and citations to that output.

Table 5-25
OECD share of world S&E literature cited in S&E articles: 2001

Country	Percent
All OECD	94.1
United States	43.6
United Kingdom	8.2
Japan	7.3
Germany	7.1
France	4.9
Other OECD	22.9

OECD Organisation for Economic Co-operation and Development

NOTES: Citations are references to U.S. scientific articles in journals indexed and tracked by the Institute for Scientific Information's Science Citation Index and Social Sciences Citation Index. Country shares are based on citations of articles credited to an institutional address within the country. For internationally authored articles, countries are credited the fractional contribution to the article.

SOURCES: Institute for Scientific Information, Science Citation Index and Social Sciences Citation Index; CHI Research, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix table 5-48.

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compared with other regions and second most cited country (table 5-26 and appendix tables 5-49 and 5-50). The relative citation indexes of the Western European countries, whose S&E literature is also frequently cited by the United States and other regions, especially Eastern Europe/Central Asia, are also high. Measured by relative citation index, Switzerland is the most highly cited country in the world and the top-cited country in the fields of engineering and technology (with an especially high index of 1.8) and biology and shares the top spot with the United States in biomedical research.

Table 5-26
Relative prominence of citations of S&E literature, by region: 1994 and 2001
Relative citation index

Country/region	1994	2001
United States	1.01	1.01
Western Europe	0.67	0.72
Asia	0.43	0.41
Eastern Europe/Central Asia	0.13	0.23
Near East/North Africa	0.47	0.53
Pacific	0.59	0.64
Central/South America	0.31	0.37
Sub-Saharan Africa	0.30	0.36

NOTE: Relative citation index is the frequency of citation of a country or region's scientific literature outside of its own region, adjusted for its world share of S&E articles.

SOURCES: Institute for Scientific Information, Science Citation Index and Social Sciences Citation Index; CHI Research, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix table 5-49.

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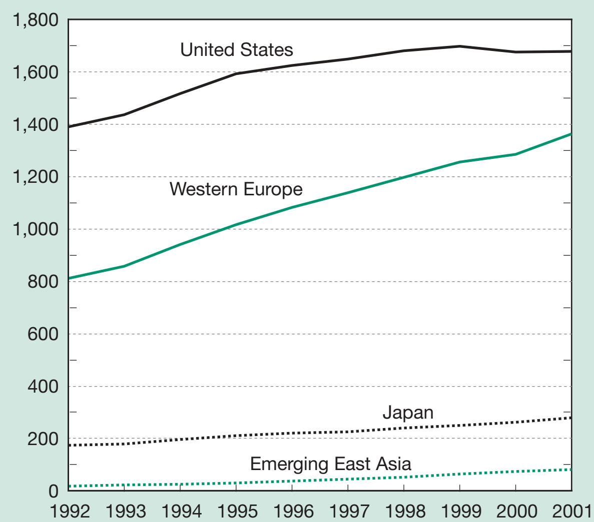
In contrast to the OECD countries, the emerging and developing countries were cited 25 to 75 percent less relative to their worldwide share of S&E articles (appendix table 5-50). In specific scientific fields, however, the relative citation indexes of a few emerging/developing countries rival those of the OECD countries. For example, Chile is the second most cited country in the earth and space sciences, and Slovenia is highly cited in mathematics.

The volume of cited scientific literature increased 43 percent between 1992 and 2001, largely driven by citation of the literature of the same regions and countries that spurred the growth in the output of scientific articles: Western Europe, Japan, and several emerging East Asian S&T centers (figure 5-41). Citation of Western European literature grew by 68 percent between 1992 and 2001, pushing this region's share of the world's cited literature from 30 to 35 percent. The increase in citation of Western European literature was led by many of same countries with dynamic growth in output of scientific articles, smaller and newer members of the EU such as Spain, Portugal, and Ireland. Citation of Japanese literature also rose substantially, increasing at roughly the same rate as Western European literature.

Citation of literature from East Asian authors in China, Singapore, South Korea, and Taiwan more than quadrupled in volume during this period, with the collective share of these countries rising from 0.7 percent of the world's cited literature in 1992 to 2.1 percent in 2001. Despite the dramatic growth in the citation volume of these countries, their

Figure 5-41
Scientific research cited in S&E articles, by selected countries/regions: 1992–2001
Thousands of articles



NOTE: Emerging East Asia consists of China, Singapore, South Korea, and Taiwan.

SOURCES: Institute for Scientific Information, Science Citation Index and Social Sciences Citation Index; CHI Research, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix table 5-48.

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relative citation indexes did not increase markedly between 1994 and 2001 (appendix table 5-50), a stability that may reflect, in part, the concentration of these countries' international ties with the United States and within Asia and/or their very rapid growth in article output.

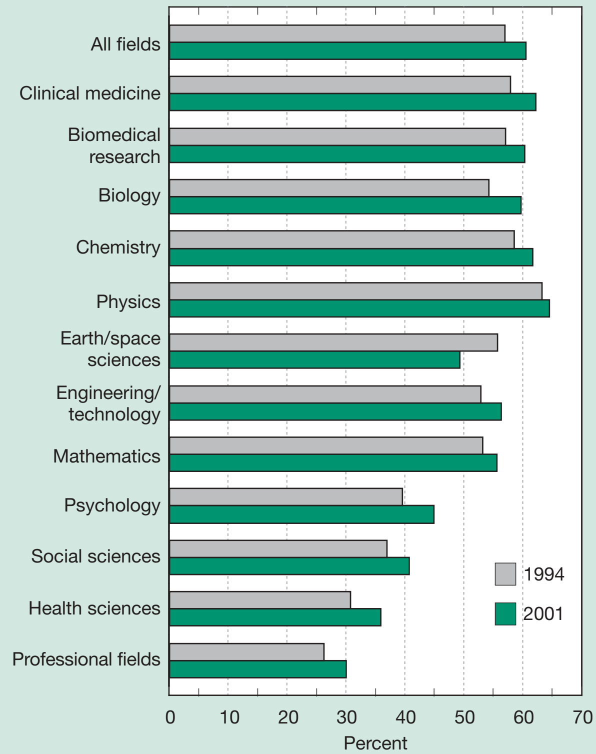
The volume of cited U.S. scientific literature, however, flattened during the mid-1990s, with its share of cited world S&E literature falling from 52 percent in 1992 to 44 percent in 2001 (appendix table 5-48). This flattening in citation of U.S. literature occurred across almost all fields and mirrored the trend of flat U.S. output of S&E articles during this period (table 5-27). On a relative basis, however, the rate of citation of U.S. literature remained unchanged (table 5-26 and appendix tables 5-49 and 5-50).

Other regions and countries also saw their citation volume increase. Between 1992 and 2001, citation of literature from Central and South America almost tripled, that from Eastern Europe/Central Asia and the Near East/North Africa rose by about one-half, and that from sub-Saharan Africa rose 17 percent. The citation volume of Indian literature, the second most widely cited in Asia, rose by 70 percent during this period.

The increase in citation volume in most regions coincided with a growing share of citations to work done outside of the author's country. The rate of citing foreign research varied by field, with high shares in physics, mathematics, and engineering and technical fields, and the lowest shares in the social and behavioral sciences (figure 5-42). Averaged across all fields, 62 percent of all citations in 2001 were to S&E literature produced outside the author's country, compared with 55 percent in 1992. This overall rate masks the United States' much lower rate of citing foreign S&E literature in comparison with the rest of the world (appendix table 5-51).

The country whose S&E literature was cited most by U.S. authors between 1994 and 2001 was the United Kingdom, followed by Germany, Japan, Canada, France, and other Western European countries (table 5-28). Worldwide, many citations of foreign S&E literature were to centers with a well-developed S&T base: the United States, Western

Figure 5-42
Foreign S&E literature cited in the world's S&E articles: 1994 and 2001



NOTES: Citations are references to articles in journals covered by the Institute for Scientific Information's Science Citation Index and Social Sciences Citation Index. Citation counts are based on a 3-year window with a 2-year lag. For example, citations for 2001 are references made in articles published in 2001 to articles published in 1997–99. Computer sciences are included in engineering and technology.

SOURCES: Institute for Scientific Information, Science Citation Index and Social Sciences Citation Index; CHI Research, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix table 5-51.

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Table 5-27
Citations of U.S. S&E articles, by field: Selected years, 1992–2001

Field	1992	1994	1996	1997	1999	2001
All fields	1,389,314	1,516,264	1,624,607	1,648,899	1,696,859	1,678,293
Clinical medicine	475,793	516,665	554,332	574,859	584,330	589,762
Biomedical research	460,148	518,304	562,361	572,122	594,596	568,328
Biology	52,535	57,825	58,649	58,130	56,981	57,899
Chemistry	88,010	96,827	105,960	105,762	110,927	109,703
Physics	137,922	141,653	138,417	131,958	125,968	120,593
Earth/space sciences	55,086	58,818	71,230	73,507	83,053	82,614
Engineering/technology	32,680	35,189	33,664	32,958	34,001	36,809
Mathematics	6,858	6,631	6,961	6,418	7,520	7,794
Social/behavorial sciences	80,282	84,353	93,032	93,187	99,481	104793

NOTES: Social/behavorial sciences include social sciences, psychology, health sciences, and professional fields. Computer sciences are included in engineering and technology. Fields counts may not sum to total due to rounding.

SOURCES: Institute for Scientific Information, Science Citation Index and Social Sciences Citation index; CHI Research, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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Table 5-28
Countries whose S&E articles were cited most in U.S. S&E articles: 1994 and 2001

	1994		2001	
Rank	Country	Percent	Country	Percent
1	United Kingdom	17.8	United Kingdom	16.0
2	Japan	12.4	Germany	12.7
3	Germany	11.9	Japan	11.9
4	Canada	10.4	Canada	8.9
5	France	9.2	France	8.7
6	Netherlands	4.5	Italy	5.1
7	Italy	4.2	Netherlands	4.5
8	Switzerland	3.9	Australia	3.9
9	Sweden	3.7	Switzerland	3.8
10	Australia	3.7	Sweden	3.2

NOTE: Countries ranked by share of foreign S&E literature cited in U.S.-authored scientific articles.

SOURCES: Institute for Scientific Information, Science Citation Index and Social Sciences Citation Index; CHI Research, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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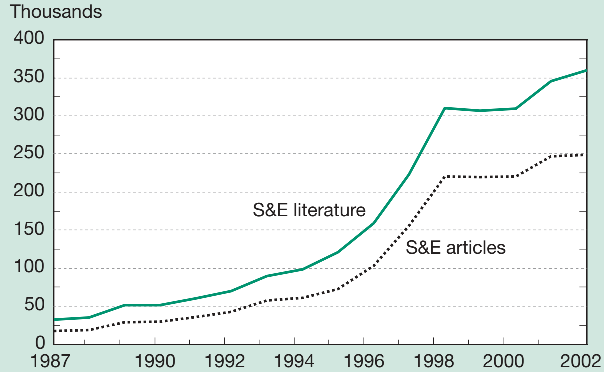
Europe, and, to some extent, Japan and the emerging East Asian countries. The exception to this is Western Europe, where about half of the citations are intraregional, consistent with the region's high degree of intraregional collaboration.

Citations in U.S. Patents to S&E Literature

U.S. patents cite previous source material to help meet the application criteria of the U.S. Patent and Trademark Office (PTO).[50] Although existing patents are the most often cited material, U.S. patents increasingly have cited scientific articles. This growth in citations of S&E literature, referenced by scientific field, technology class of the patent, and the nationality of the inventor and cited literature, provide an indicator of the link between research and practical application.[51]

The number of U.S. patent citations to S&E articles indexed in the Institute for Scientific Information's SCI rose more than 10-fold between 1987 and 2002 (figure 5-43).[52] Even as the number of patents rose rapidly, the average number of citations per U.S. patent increased more than sixfold during this period (figure 5-44).

Figure 5-43
Citations of S&E literature in U.S. patents: 1987–2002



NOTES: Citations to S&E articles are references to S&E articles in journals indexed and tracked by the Institute for Scientific Information's Science Citation Index. Citations to S&E literature are references to S&E articles within and outside of ISI's coverage and non-article material such as reports, technical notes, conference proceedings, etc. Citation counts are based on a 12-year window with a 3-year lag. For example, citations for 2000 are references made in U.S. patents issued in 2000 to articles published in 1986-97. Patent data for 2002 are preliminary and subject to change.

SOURCES: U.S. Patent and Trademark Office; Institute for Scientific Information, Science Citation Index; CHI Research, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix table 5-52.

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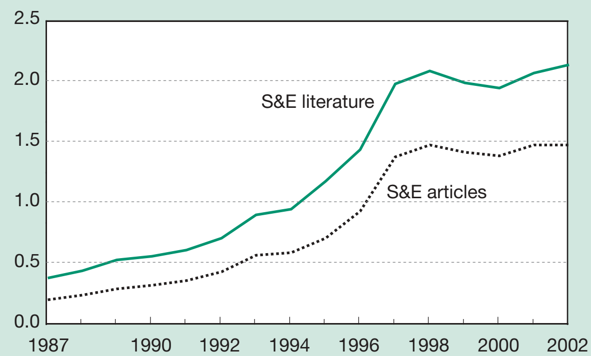
Figure 5-44
Citations of S&E literature per U.S. patent: 1987–2002



NOTES: Citations to S&E articles are references to S&E articles in journals indexed and tracked by the Institute for Scientific Information's Science Citation Index. Citations to S&E literature are references to S&E articles within and outside of ISI's coverage and non-article material such as reports, technical notes, conference proceedings, etc. Citation counts are based on a 12-year window with a 3-year lag. For example, citations for 2000 are references made in U.S. patents issued in 2000 to articles published in 1986-97. Patent data for 2002 are preliminary and subject to change.

SOURCES: U.S. Patent and Trademark Office; Institute for Scientific Information, Science Citation Index; CHI Research, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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[50]The U.S. Patent and Trademark Office evaluates patent applications on the basis of whether the invention is useful, novel, and nonobvious. The novelty requirement leads to references to other patents, scientific journal articles, meetings, books, industrial standards, technical disclosures, etc. These references are termed *prior art.*

[51]Citation data must be interpreted with caution. The use of patenting varies by type of industry, and many citations on patent applications are to prior patents. Patenting is only one way that firms seek returns from innovation and thus reflects, in part, strategic and tactical decisions (e.g., laying the groundwork for cross-licensing arrangements). Most patents do not cover specific marketable products but might conceivably contribute in some fashion to one or more products in the future. (See Geisler 2001.)

[52]Citations are references to S&E articles in journals indexed and tracked by the Institute for Scientific Information in its Science Citation Index and Social Sciences Citation Index. Citation counts are based on articles published within a 12-year period that lagged 3 years behind the issuance of the patent. For example, citations for 2000 are references made in U.S. patents issued in 2000 to articles published in 1986–97.

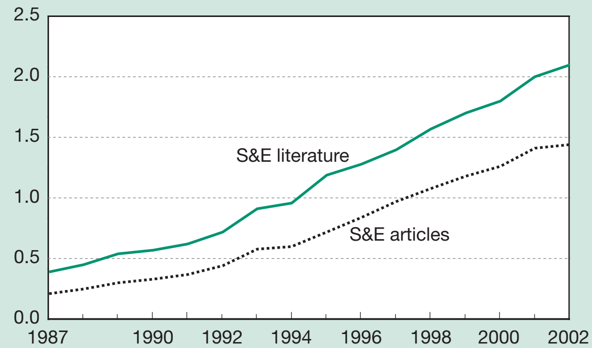
Growth of Referencing in Patents

During the past decade, the rate at which scientific papers are referenced in patents has increased rapidly. The causes of this growth are complex, but they appear to include changes made in the patent law in 1995. These changes, enacted to comply with the General Agreement on Tariffs and Trade (GATT), changed the term of patent protection from 17 years from the award date to 20 years from the filing date for applications received after June 8, 1995. Previously rejected patents refiled after this date would also be subject to the GATT rules. Applications submitted to the U.S. Patent and Trademark Office more than doubled in May and June of 1995. These applications carried an unusually large number of references to scientific material. Patents applied for in June 1995 carried three times the number of scientific references of those filed in March 1995 and six times the number of those filed in July 1995. This sudden increase in referencing affected patents in all technologies, not just those in biotechnology and pharmaceuticals, in which referencing is most extensive.

The surge in applications during this period suggests that applicants and their attorneys rushed to file their patents under the old rules, perhaps out of caution and uncertainty about the GATT rules. One source of uncertainty in the application process at the time, affecting especially biotechnology, was ambiguity about what constituted adequate written description. Because a rejected application would have to be refiled under the GATT rules, referencing a great deal of scientific material may have been a strategy to minimize the chance of rejection for inadequate written description.

Patents applied for in May and June 1995 were issued gradually over the next few years. As these patents were issued, the rate of referencing increased rapidly. However, after the last of these applications were processed, the rate of referencing fell again to levels closer to those found earlier. In fact, if these patents are eliminated from consideration, a more gradual long-term trend of increased referencing is evident (figure 5-45).

Figure 5-45
Citations of S&E literature per U.S. patent, excluding "spike" patents: 1987–2002



NOTES: Citations to S&E articles are references to S&E articles in journals indexed and tracked by the Institute for Scientific Information's Science Citation Index. Citations to S&E literature are references to S&E articles within and outside of ISI's coverage and non-article material such as reports, technical notes, conference proceedings, etc. Citation counts are based on a 12-year window with a 3-year lag. For example, citations for 2000 are references made in U.S. patents issued in 2000 to articles published in 1986-97. "Spike" patents are those with an application date of May–June 1995. Patent data for 2002 are preliminary and subject to change.

SOURCES: U.S. Patent and Trademark Office; Institute for Scientific Information, Science Citation Index; CHI Research, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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The rapid growth of article citations in patents throughout much of the past decade was centered in huge increases in the life science fields of biomedical research and clinical medicine. Between 1995 and 2002, these fields accounted for 75 percent of the increase in total patent citation volume, and their share increased from 61 to 70 percent (appendix table 5-52).

The growth of citations of scientific research in patents attests to the increasing link between research and practical applications. The growth in citations has been driven, in part, by increased patenting of research-driven products and processes, primarily in the life sciences.[53] In addition, changes in practices and procedures in the U.S. PTO may have increased the incentive for and ease of citing scientific literature. (See sidebar, "Growth of Referencing in Patents.")

The bulk of U.S. patents citing scientific literature were issued to U.S. inventors, who accounted for 65 percent of these patents in 2001, a share that has been disproportionately higher than the U.S. inventor share of all U.S. patents since the past decade. Other key inventor regions and countries of U.S. patents that cite scientific literature are Western Europe (17 percent), including France (3 percent), Germany (5 percent), and the United Kingdom (3 percent); Japan (11 percent); emerging East Asia (2 percent); and Canada (3 percent) (table 5-29).

Examination of the share of cited literature in the United States, Western Europe, and Asia, adjusted for their respective world output share of scientific literature (relative citation index) and excluding citation of literature from the inventor's own country or region, suggests that inventors outside the United States, primarily those from Western Europe and Asia, frequently cite U.S. scientific literature (table 5-30). This is comparable to the high rate of citation of U.S. scientific literature by scientists in these regions. In addition, Asian physics articles are highly cited by inventors outside of Asia.

[53]See discussion in following section, "Patents Awarded to U.S. Universities."

Table 5-29
U.S. patents that cite S&E literature, by nationality of inventor: 1990, 1996, and 2001

	1990 U.S. patents		1996 U.S. patents		2001 U.S. patents	
	Total	Citing S&E literature	Total	Citing S&E literature	Total	Citing S&E literature
	Number					
U.S. patents	90,379	6,367	109,687	12,894	166,039	21,155
Nationality of inventor	Percent distribution					
Worldwide	100.0	100.0	100.0	100.0	100.0	100.0
North America	54.5	64.9	57.6	66.8	55.0	68.1
Canada	2.1	1.7	2.0	2.0	2.2	2.6
Mexico	0.0	0.1	0.0	0.1	0.0	0.0
United States	52.4	63.1	55.5	64.7	52.8	65.4
Western Europe	21.1	18.3	16.4	15.5	18.1	16.8
France	3.2	3.0	2.6	2.7	2.4	2.5
Germany	8.4	6.1	6.2	4.5	6.8	4.8
Italy	1.4	0.8	1.1	0.8	1.0	0.9
Netherlands	1.1	1.3	0.7	0.8	0.8	0.9
Sweden	0.8	0.4	0.8	0.7	1.0	0.9
Switzerland	1.4	1.7	1.1	0.9	0.9	1.1
United Kingdom	3.1	3.7	2.3	3.1	3.2	3.3
Other	1.6	1.3	1.6	1.9	2.0	2.3
Asia	22.8	15.6	24.3	15.9	25.9	12.7
Japan	21.6	15.2	21.0	14.7	20.0	10.6
Emerging East Asia	1.2	0.3	3.3	1.1	5.8	1.8
Other	0.0	0.1	0.0	0.1	0.1	0.3
Other regions/countries	1.6	1.3	1.7	1.8	1.6	2.4

NOTES: Emerging East Asia consists of China, Hong Kong, Singapore, South Korea, and Taiwan. The number of U.S. patents and nationality of inventor are based on U.S. patents that reference S&E articles in journals classified and tracked by the Institute of Scientific Information's Science Citation Index. Percents may not sum to 100 because of rounding.

SOURCES: U.S. Patent and Trademark Office; Institute for Scientific Information, Science Citation Index; CHI Research, Inc.; National Science Foundation, Division of Science Resources Statistics, special tabulations.

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U.S. patents most commonly cite articles authored within the academic sector, primarily the life science fields of clinical medicine and biomedical research.[54] In 2002, the U.S. academic sector accounted for 61 percent of total citations, with almost three-fourths of these citations to clinical medicine and biomedical research (appendix table 5-53). The U.S. academic sector also had a strong presence in physics and engineering and technology, accounting for about half the citations in these fields. Between 1995 and 2002, the academic sector share increased in physics (from 40 to 51 percent) and engineering and technology (from 44 to 49 percent) coinciding with stagnating output of articles authored within the industrial sector. Industry was the next most widely cited sector (19 percent share), with articles in the fields of physics and engineering and technology prominently represented (38 and 42 percent, respectively).

The life sciences, particularly biomedical research and clinical medicine, dominated nearly every sector, with from 67 to more than 90 percent of all citations (appendix table 5-53). This included sectors that had prominent citation shares in the physical sciences earlier in the decade (industry and FFRDCs). They experienced significant declines in citations of articles in these fields, whereas their share of life sciences citations grew significantly.

Patents Awarded to U.S. Universities

The results of academic S&E research increasingly extend beyond articles in S&E journals to patent protection of research-derived inventions.[55] Patents are an indicator of the efforts of academic institutions to protect the intellectual property of their inventions, technology transfer,[56] and industry-university collaboration. The rise of patents received by U.S. universities attests to the increasingly important role of academic institutions in creating and supporting knowledge-based industries closely linked to scientific research.

Patenting by academic institutions has markedly increased over the past 3 decades, rising from about 250–350 patents annually in the 1970s to more than 3,200 patents in

[54]U.S. performer data is restricted to U.S. citations of U.S. literature in the Institute for Scientific Information journal set.

[55]Research articles also are increasingly cited in patents, attesting to the close relationship of some basic academic research to potential commercial application. See the previous section, "Citations in U.S. Patents to S&E Literature."

[56]Other means of technology transfer are industry hiring of students and faculty, consulting relationships between faculty and industries, formation of firms by students or faculty, scientific publications, presentation at conferences, and informal communications between industrial and academic researchers.

Table 5-30
Citation of S&E literature in U.S. patents relative to share of S&E literature, by selected field and country/region: 2002
Relative citation index

Field and country/region of citing inventor	United States	Western Europe	Asia
All fields	1.23	0.69	0.64
Clinical medicine	1.19	0.69	0.65
Biomedical research	1.30	0.65	0.50
Chemistry	1.59	0.72	0.55
Physics	1.25	0.55	1.05
Engineering/technology	1.15	0.71	0.69

NOTES: Relative citation index is the frequency of citation of a country or region's S&E literature by U.S. patents, adjusted for its world share of S&E articles. Citations of the country's own literature are excluded. An index of 1.00 would indicate that the region's share of cited literature was equal to its world share of S&E literature. An index greater or less than 1.00 would indicate that the region was cited relatively more or less frequently than indicated by its share of world S&E literature. Citations are references to S&E articles in journals indexed and tracked by the Institute for Scientific Information's Science Citation Index and Social Sciences Citation Index. Citation counts are based on a 6-year window with a 2-year lag, i.e., citations for 2002 are references made in U.S. patents issued in 2002 to articles published in 1995–2000. Scientific field is determined by CHI's classification of the journal. Computer sciences are included in engineering and technology. Patent data for 2002 are preliminary and subject to change.

SOURCES: U.S. Patent and Trademark Office; Institute for Scientific Information, Science Citation Index and Social Sciences Citation Index; CHI Research, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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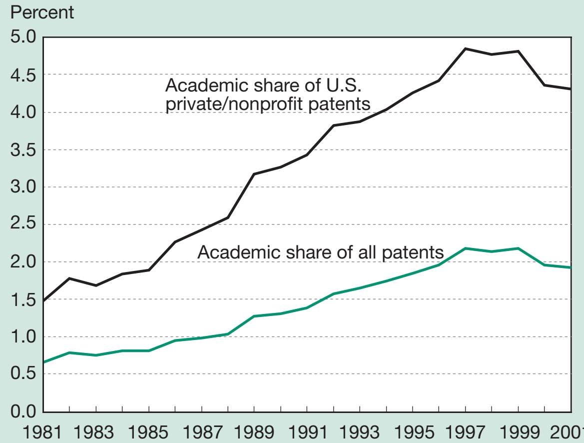
Figure 5-46
Significance of U.S academic patenting activity: 1981–2001



NOTES: Patents issued by U.S. Patent and Trademark Office to U.S. universities and corporations. U.S. private/nonprofit sector includes U.S. corporations (which are issued the bulk of patents in this category), nonprofits, small businesses, and educational institutions. All patents include U.S. patents issued to U.S. and non-U.S. organizations and individual inventors.

SOURCES: U.S. Patent and Trademark Office (USPTO), *Technology Assessment and Forecast Report: U.S. Colleges and Universities, Utility Patent Grants, 1969–2001* (Washington, DC, 2001); and USPTO, special tabulations.

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2001 (appendix table 5-54; see also NSB 1996, appendix table 5-42). The share of academic patents has also risen significantly, even as growth in all U.S. patents increased rapidly during this period. For example, U.S. academic institutions accounted for more than 4 percent of patents granted to the U.S. private and nonprofit sectors in 2001, compared with less than 1.5 percent in 1981. The share, however, was down slightly from a peak of almost 5 percent during 1997–99 (figure 5-46).

During this period, the number of academic institutions receiving patents increased rapidly, nearly doubling in the 1980s to more than 150 institutions and continuing to grow to reach 190 institutions in 2001 (appendix table 5-54).[57] Both public and private institutions participated in this rise.

Despite the increase in institutions receiving patents, the distribution of patenting activity has remained highly concentrated among a few major research universities. The top 25 recipients accounted for more than 50 percent of all academic patents in 2001, a share that has remained constant for 2 decades. These institutions also account for a disproportionate share (40 percent in 2001) of all R&D expenditures by academic patenting institutions. Including the next 75 largest recipients increases the share to more than 90 percent of patents granted to all institutions in 2001 and much of the 1990s. Many smaller universities and colleges began to receive patents in the 1980s, which pushed the large institutions' share as low as 82 percent, but the trend reversed in the 1990s (appendix table 5-54). Several factors appear to have driven the rise in academic patenting:

- **The Bayh-Dole University and Small Business Patent Act.** Passed in 1980, this law[58] permitted government grantees and contractors to retain title to inventions resulting from federally supported R&D and encouraged the licensing of such inventions to industry. Although some Federal agencies permitted universities to retain title before Bayh-Dole, this law established a uniform government-wide policy and process for academic patenting.
- **Emerging and Maturing Research-Based Industries**. During the 1990s, industries emerged and matured that used commercial applications derived from "use-oriented" basic research in life sciences fields such as molecular biology and genomics (Stokes 1997).

[57]The institution count is a conservative estimate because several university systems are counted as one institution, medical schools are often counted with their home institution, and universities are credited for patents on the basis of being the first-name assignee on the patent, which excludes patents where they share credit with another first-name assignee. Varying and changing university practices in assigning patents, such as to board of regents, individual campuses, or entities with or without affiliation to the university, also contribute to the lack of precision in the estimate. The data presented here have been aggregated consistently by the U.S. Patent and Trademark Office since 1982.

[58]The Bayh-Dole Act of 1980 (Public Law 96-517) allows researchers or universities financed partially or completely by Federal funding to own their inventions.

- **Strengthening of Patent Protection.** Changes in the U.S. patent regime strengthened overall patent and copyright protection and encouraged the patenting of biomedical and life sciences technology. The creation of the Court of Appeals of the Federal Circuit to handle patent infringement cases was one factor in the strengthening of overall patent protection. The Supreme Court's landmark 1980 ruling in *Diamond* v. *Chakrabarty,* which allowed patentability of genetically modified life forms, also may have been a major stimulus behind the recent rapid increases.

The growth in academic patents occurred primarily in the life sciences and biotechnology (Huttner 1999). Patents in two technology areas or "utility classes," both with presumed biomedical relevance, accounted for 39 percent of the academic total in 2001, up from less than a fourth in the early 1980s. The class that experienced the fastest growth—chemistry, molecular biology, and microbiology—increased its share from 8 percent to 21 percent during this period (figure 5-47).

A survey by the Association of University Technology Managers (AUTM), which tracks several indicators of academic patenting, licensing, and related practices, attests to the expansion of patenting and related activities by universities (table 5-31). The number of new patent applications more than quadrupled between FYs 1991 and 2001,[59] indicating the growing effort and increasing success of universities obtaining patent protection for their technology.

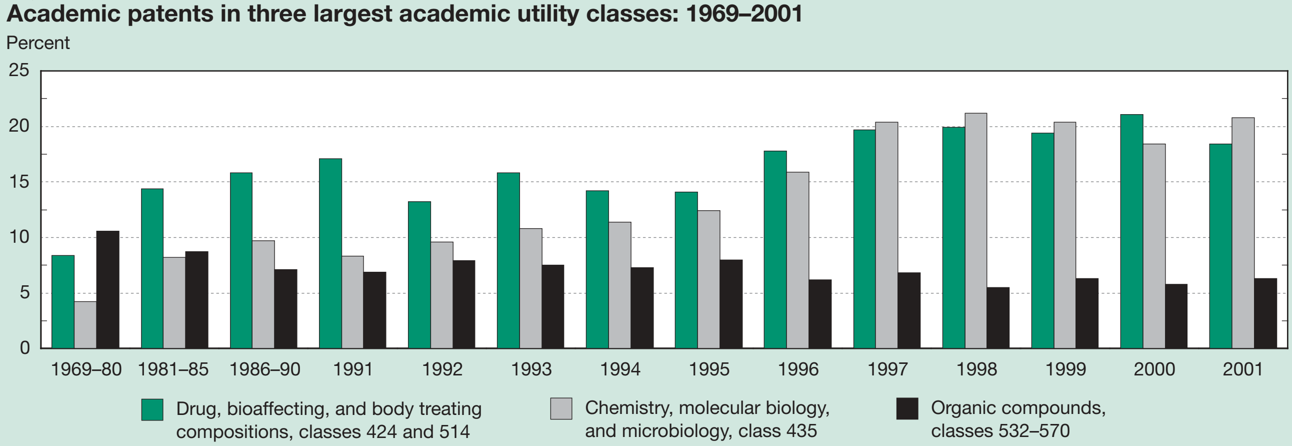
Two indicators related to patents—invention disclosures and new licenses and options—provide a broader picture of university efforts to exploit their technology. Invention disclosures, which describe the prospective invention and are submitted before a patent application or negotiation of a licensing agreement, rose sharply during this period. New licenses and options, indicating the commercialization of university-developed technology, also rose by more than half since FY 1996.

Obtaining patent protection does not always precede negotiation of a licensing agreement, underscoring the embryonic nature of university-developed technology. According to a recent survey of more than 60 major research universities, 76 percent of respondents reported that they "rarely" or "sometimes" had patent or copyright protection at the time of negotiating the licensing agreement, whereas 25 percent responded "often" or "almost always" (Thursby et al. 2001).[60] In addition, most inventions were at a very early stage of development when the licensing agreement was negotiated, and nearly half the respondents characterized their inventions as a proof of concept rather than a prototype (table 5-32).

The majority of licenses and options (66 percent) are conducted with small companies (existing companies or startups), most likely influenced by the Bayh-Dole Act's mandate that universities give preference to small businesses (figure 5-48). In cases of unproven or very risky technology, universities often opt to make an arrangement with a startup company because existing companies may be unwilling to take on the risk. Faculty involvement in startups may also play a key role in this form of alliance. The majority of licenses granted to small companies and startups are exclusive, that is, they do not allow the technology to be commercialized by other companies.

With the steady increase of revenue-generating licenses and options, income to universities from patenting and licenses has grown substantially over the past decade, reaching more than $850 million in FY 2001—more than half

Figure 5-47
Academic patents in three largest academic utility classes: 1969–2001



SOURCES: U.S. Patent and Trademark Office (USPTO), *Technology Assessment and Forecast Report: U.S. Colleges and Universities, Utility Patent Grants, 1969–2001* (Washington, DC, 2001); and USPTO, special tabulations.

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[59]Universities report data to AUTM on a fiscal-year basis, which varies across institutions.

[60]Sum exceeds 100 percent because of rounding.

Table 5-31
Academic patenting and licensing activities: 1991–2001

Indicator of activity	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
	Number										
Academic institutions reporting	98	98	117	120	127	131	132	132	139	142	139
	Millions of dollars										
Net royalties	NA	NA	195.0	217.4	239.1	290.1	391.1	517.3	583.0	1,012.0	753.9
Gross royalties	130.0	172.4	242.3	265.9	299.1	365.2	482.8	613.6	675.5	1,108.9[a]	868.3
Royalties paid to others	NA	NA	19.5	20.8	25.6	28.6	36.2	36.7	34.5	32.7	41.0
Unreimbursed legal fees expended	19.3	22.2	27.8	27.7	34.4	46.5	55.5	59.6	58.0	64.2	73.4
New research funding from licenses[b]	NA	NA	NA	106.3	112.5	155.7	136.2	126.9	149.0	184.0	NA
	Number										
Invention disclosures received	4,880	5,700	6,598	6,697	7,427	8,119	9,051	9,555	10,052	10,802	11,259
New U.S. patent applications filed	1,335	1,608	1,993	2,015	2,373	2,734	3,644	4,140	4,871	5,623	5,784
U.S. patents granted	NA	NA	1,307	1,596	1,550	1,776	2,239	2,681	3,079	3,272	3,179
Startup companies formed	NA	NA	NA	175	169	184	258	279	275	368	402
Revenue-generating licenses and options	2,210	2,809	3,413	3,560	4,272	4,958	5,659	6,006	6,663	7,562	7,715
New licenses and options executed	1,079	1,461	1,737	2,049	2,142	2,209	2,707	3,078	3,295	3,569	3,300
Equity licenses and options	NA	NA	NA	NA	99	113	203	210	181	296	NA
	Percent[c]										
Sponsored research funds	65	68	75	76	78	81	82	83	82	86	84
Federal research funds	79	82	85	85	85	89	90	90	90	92	92

NA not available

[a]Includes one-time payments of equity cash in and funds received from settlement of a patent infringement suit.
[b]Directly related to a license or option agreement.
[c]Of national academic total represented by number of academic institutions reporting.

SOURCE: Association of University Technology Managers, AUTM Licensing Survey (Norwalk, CT, various years).

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Table 5-32
Stage of development of licensed inventions by U.S. universities: 1998
(Percent)

Stage of development	Invention disclosures
Proof of concept but no prototype	45.1
Prototype available but only lab scale	37.2
Some animal data available	26.7
Some clinical data available	9.5
Manufacturing feasibility known	15.3
Ready for practical commercial use	12.3

NOTES: Survey of patenting and licensing offices at 62 U.S. research universities. Sum of shares exceeds 100 percent because some respondents indicated more than one stage of development.

SOURCE: J. Thursby, R. Jensen, and M. Thursby, Objectives, characteristics and outcomes of university licensing: A survey of major U.S. universities, *Journal of Technology Transfer* 26:59–72, 2001.

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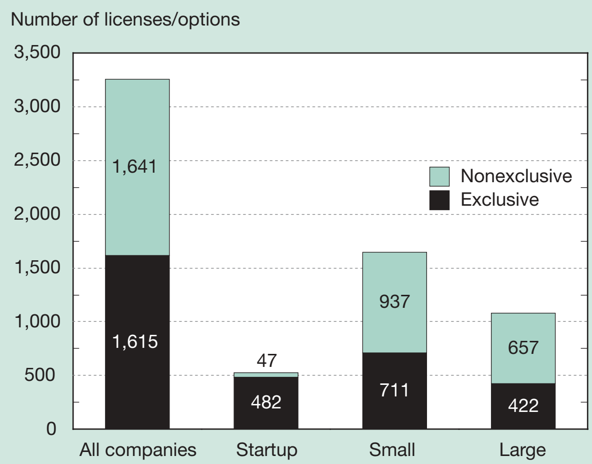
Figure 5-48
Characteristics of licenses and options executed by U.S. universities: 2000



NOTES: Exclusive agreements do not allow sharing or marketing of the technology to other companies, whereas it is permitted under nonexclusive agreements.

SOURCE: Association of University Technology Managers, AUTM Licensing Survey: FY 2000 (Norwalk, CT, 2002).

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the FY 1996 level.[61] Licensing income, however, is only a fraction of overall academic research spending, amounting to less than 4 percent in FY 2001.[62]

The 1999 AUTM survey found that about half of universities' royalties were concentrated in technology related to the life sciences. The survey categorized one-third of the remaining royalties as "not classified" and the remainder as being in the physical sciences, which appears to include engineering. Licensing income is also highly concentrated among a few universities and blockbuster patents. For example, the 2000 AUTM survey found that less than 1 percent of active licenses generated more than $1 million in income in FY 2000, a figure that includes licenses held by U.S. universities and hospitals, Canadian institutions, and patent management firms.

Because data on costs are not available, it is unclear whether universities break even or profit from their technology transfer activities. Gross revenue is allocated among the university, the inventor (who typically receives a 30–50 percent share), and costs such as patent and license management fees, which can be considerable (Sampat 2002).[63] One study estimated that 58 percent of universities surveyed made a profit on their patenting and licensing activities in 1996 (Trune and Goslin 2000).

University-industry collaboration and successful commercialization of academic research in the United States contributed to the rapid transformation of new and often basic knowledge into industrial innovations, including new products, processes, and services. Other nations, seeing these benefits, are endeavoring to import these and related practices in an effort to strengthen innovation. (See sidebar, "Academic Patenting and Licensing in Other Countries"). In the United States, however, scholars and policymakers are debating whether academic patenting and related activities led to unintended or potentially harmful effects. (See sidebar, "Debate Over Academic Patenting in the United States.")

Academic Patenting and Licensing in Other Countries

Beginning in the mid-1990s, several countries, particularly members of the Organisation for Economic Co-operation and Development (OECD), sought to encourage and increase commercialization of technology developed at universities and other publicly supported research institutions (table 5-33). The focus has been on clarifying and strengthening ownership and exploitation of an institution's intellectual property and on granting ownership of intellectual property to universities and other public research organizations (PROs) in countries where the inventor or government was the owner. The justification for these legal and policy changes is that institutional ownership provides greater legal certainty, lowers transaction costs, and fosters more formal and efficient channels for technology transfer as compared with ownership by the government or the inventor (OECD 2002). Changes in intellectual property protection of academic institutions were through a variety of means, including reforming national patent policies, employment law, and research funding regulation and clarifying policy and administrative procedures of technology license offices.

The motivation for consideration and change of these countries' regulations and policies is due to a variety of factors (OECD 2002; Mowery and Sampat 2002):

- ♦ **Emulation of the United States.** Many countries believe that the United States has been very successful at commercializing its university technology, especially following the passage of the Bayh-Dole Act, which they consider a key factor in allowing the United States to benefit economically from its scientific research through encouraging and speeding up the commercialization of university inventions. This is especially true of European countries that would like to create indigenous science-based industries and believe that the level of commercialization from their public R&D is inadequate.
- ♦ **Exploitation of Inventions Developed From Publicly Funded Research.** There is concern that current regulations and practices limit and slow the commercialization of technology developed from publicly funded research. Countries would like a greater commercial return from their investments in public scientific research and believe that strengthening and clarifying policies toward licensing and patenting will encourage and speed up commercialization.
- ♦ **Generation of Licensing Revenues.** Countries believe an increase in patenting and licensing by universities will increase revenue from licensing technology, which could support university technology activities or university research. Some countries, however, acknowledged that licensing offices lose money on their operations, and are considering subsidizing their operations with public funding
- ♦ **Formation of Spinoff Companies.** Countries believe that commercialization of university-developed tech-

[61]Licensing income for 2000 was boosted by several one-time payments, including a $200 million settlement of a patent infringement case, and by several institutions' cashing in of their equity held in licensee companies.

[62]See *Academic Research and Development Expenditures: Fiscal Year 2001* (NSF/SRS 2003). This is a rough estimate because of the lack of data on the R&D expenditures of a few smaller institutions.

[63]Thursby et al. (2001) report that universities allocate an average of 40 percent of net income to the inventors, 16 percent to the inventor's department or school (often returned to the inventor's laboratory), 26 percent to central administrations, and 11 percent to technology transfer offices, with the remainder allocated to "other."

nology could yield formation of startup companies. Forming spinoff companies is viewed as desirable for creating new high-technology or science-based jobs and industries, fostering entrepreneurial skills and culture, and increasing competition among existing firms.

- **Promotion of International Scientific Collaboration.** The EU countries, in particular, are concerned that differing national laws and policies, particularly ownership of university technology, inhibit scientific collaboration within the EU by raising transaction costs due to legal complications and uncertainty.

The OECD conducted a survey in 2001 of member countries' technology transfer offices and examined national laws and regulations. The survey found that in countries that enacted legislation, awareness of and support for technology transfer increased among the major stakeholders, although relatively little growth in patenting, licensing, or spinoffs occurred. In addition, most licensing of technology from universities and public research organizations is based on nonpatentable inventions. These findings raise the question of whether specific features of the U.S. education, research, and legal systems play a key part in the commercialization of the results of academic research and development in the United States.

Table 5-33
Ownership of academic intellectual property in OECD countries: 2003

	Owner of invention			
Country	University	Faculty	Government	Status/recent initiatives
Australia	x	na	na	
Austria	x	na	na	
Belgium	x	na	na	
Canada[a]	x	x	na	
Denmark	x	na	na	
Finland	na	x	na	Consideration of legislation in 2003 to restrict faculty's right to retain ownership of publicly funded research.
France	x	na	na	
Germany	x	na	na	Debate during 2001 over awarding ownership to universities.
Iceland	na	x	na	
Ireland	x	na	na	
Italy	na	x	na	Legislation passed in 2001 to give ownership rights to researchers. Legislation introduced in 2002 to grant ownership to universities and create technology transfer offices.
Japan[b]	na	x	o	Private technology transfer offices authorized in 1998.
Mexico	x	na	na	
Netherlands	x	na	na	
Norway	na	x	na	Legislation passed in 2003 to allow universities to retain ownership of publicly funded research.
Poland	x	na	na	
South Korea	x	na	na	
Sweden	na	x	na	Recent debate and consideration of legislation to allow universities to retain ownership of publicly funded research.
United Kingdom	x	o	na	Universities, rather than government, given rights to faculty inventions in 1985.
United States[c]	x	o	o	

x legal basis or most common practice
o allowed by law/rule but less common
na not applicable

[a]Ownership of intellectual property funded by institutional funds varies, but publicly funded intellectual property belongs to institution performing research.
[b]President of the national university or interuniversity institution determines right to ownership of invention by faculty member, based on discussions by invention committee.
[c]Universities have first right to elect title to inventions resulting from federally funded research. Federal Government may claim title if university does not. In certain cases, inventor may retain rights with agreement of university/Federal partner and Government.

SOURCES: Organisation for Economic Co-operation and Development, *OECD Questionnaire on the Patenting and Licensing Activities of PRO's* (Paris, 2002); and D. C. Mowery and B. N. Sampat, International emulation of Bayh-Dole: Rash or rational? Paper presented at American Association for the Advancement of Science symposium on International Trends in the Transfer of Academic Research, Boston, February 2002.

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Debate Over Academic Patenting in the United States

Scholars and policymakers expressed concern that the increase of patenting by universities may be having unintended and possibly harmful effects on universities, faculty, and the quality and direction of academic research. These concerns include:

- **University Portfolio and Mission.** Universities may be emphasizing or diverting resources toward research areas with commercial potential. Faculty who have relationships with existing firms or are involved in spinoff firms may have a conflict of interest or divert their efforts from their other research or teaching activities. This diversion of effort and resources away from noncommercial areas of research may harm or slow progress in these areas and may erode the widely held precept that universities promote knowledge for knowledge's sake.
- **Dissemination of Knowledge.** Licensing agreements often contain clauses that restrict or delay publication of research results or require researchers to obtain approval or pay costs for using their technology in upstream applications. In addition, researchers in these fields may restrict or withhold their results to maintain a competitive advantage. As a result, research progress in these fields may be hampered or slowed, which may be a critical concern in health or medical applications. In a broader sense, the concern is that withholding knowledge may erode the scientific norm of publicizing research results.
- **Technology Transfer Costs.** The costs of setting up, maintaining, and administering technology transfer activities are considerable, and evidence suggests that many universities do not make a profit on these activities. For example, patent litigation, which can be very costly and time consuming, has been increasing with the rise in university patents. The cost of technology transfer raises the question of whether the monetary and nonmonetary benefits of technology transfer outweigh the costs, or whether universities would obtain a higher return from other activities.
- **Commercialization of Technology.** The popularity of exclusive licensing agreements in university-licensed technology has raised concerns that this type of agreement results in higher costs to consumers and a slower pace of innovation and adoption of the technology. Proponents of exclusive agreements contend that exclusive licensing agreements are necessary to compensate for the risk of commercializing unproven and embryonic university technology and that the concerns of slower innovation and adoption are not warranted.

There is also debate about whether patenting of academic research results is appropriate or necessary. Critics argue that patenting is neither appropriate nor necessary for most research results, given their embryonic nature, and that transfer of university technology would occur in the absence of patenting.

Conclusion

Strengths and challenges characterize the position of academic R&D in the United States at the beginning of the 21st century. Its graduate education, linked intimately to the conduct of research, is regarded as a model by other countries and attracts large numbers of foreign students, many of whom stay after graduation. Funding of academic R&D continues to expand rapidly, and universities perform nearly half the basic research nationwide. U.S. academic scientists and engineers are collaborating extensively with colleagues in other sectors and, increasingly, with international colleagues: in 2001, one U.S. journal article in four had at least one international coauthor. Academic patenting and licensing continue to increase, and academic and other S&E articles are increasingly cited in patents, attesting to the usefulness of academic research in producing economic benefits. Academic licensing and option revenues are growing, as are spinoff companies, and universities are increasingly moving into equity positions to maximize their economic returns.

However, there are challenges to be faced and trends that bear watching. The Federal Government's role in funding academic R&D is declining. Research-performing universities increased their own funds, which now account for one-fifth of the total, but are facing financial pressures. Industry support has grown, but less than might be surmised, given the close relationship between R&D and industrial innovation. Industry support accounted for less than 7 percent of the total in 2001. Spending on research equipment as a share of all R&D expenditures declined to less than 5 percent by 2001, a trend worthy of attention.

Academic employment has undergone a long-term shift toward greater use of nonfaculty appointments, both postdocs and other positions. A researcher pool has grown independent of growth in the faculty ranks. These developments accelerated during the latter half of the 1990s, when both retirements and new hires were beginning to rise. This raises the question of how these related trends will develop in the future, when retirements are expected to further accelerate.

Another aspect of this issue is the level of foreign participation in the academic enterprise. Academia has been able to attract many talented foreign-born scientists and engineers, and the nation has benefited from their contributions. However, as the percentage of foreign-born degree holders approaches half the total in some fields, attention shifts to degree holders who are U.S. citizens. Among those, white males were earning a declining number of S&E doctorates. On the other hand, the number of S&E doctorates earned by U.S. women and members of minority groups has been increasing, and these new Ph.D. holders were more likely to enter academia than white males. By providing role models, this development will perhaps attract to the sciences and engineering some of the growing numbers of students from minority backgrounds who are expected to enroll in college over the next quarter century.

Questions arise about the changing nature of academic research and the uses of its results. The number of U.S. articles published in the world's leading S&E journals has essentially been level since the early to mid-1990s, a trend that remains unexplained. This development follows increased funding for academic R&D and coincides with reports from academic researchers that fail to show any large shift in the nature of their research. Regarding protection of intellectual property, universities moving into equity positions raise unresolved conflict-of-interest concerns for institutions and researchers. Public confidence in academia could decline should academia's research or patenting and licensing activities be perceived as violating the public interest.

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